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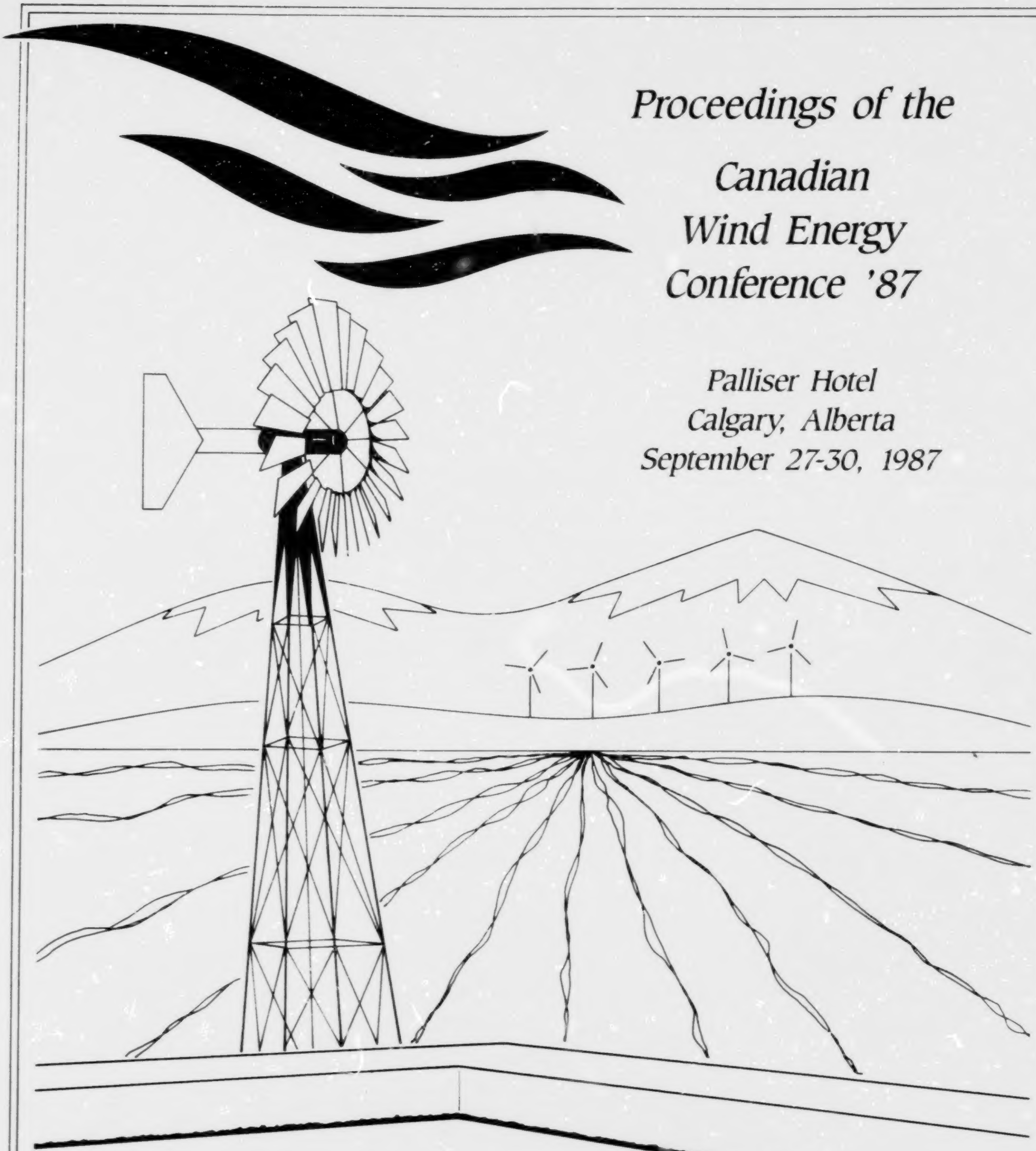

Proceedings of the Canadian Wind Energy Conference '87

Palliser Hotel
Calgary, Alberta
September 27-30, 1987

THE
CANADIAN
WIND ENERGY
ASSOCIATION

PROCEEDINGS OF THE THIRD ANNUAL NATIONAL CONFERENCE OF THE CANADIAN WIND ENERGY ASSOCIATION (CANWEA)

Calgary, Alberta
September 27 - 30, 1987

EDITED BY

Vincent P. Lacey

PRODUCED BY

Passmore Associates International
Ottawa, Ontario

SPONSORED BY

Alberta Ministry of Transportation and Utilities

JANUARY 1988

ACKNOWLEDGEMENT

The Canadian Wind Energy Association (CanWEA) would like to thank all of those who devoted their efforts to make this third conference of our association a success:

Vince Lacey of Indal Technologies and Mary-Ellen Jones of the Small Power Producers Association of Alberta, who coordinated much of the program planning;

Passmore Associates, the conference organizers, who exceeded our demands for an efficient and smoothly run conference and contributed to the conference in so many ways; and

our sponsors, Energy Mines and Resources Canada who helped make the conference possible; and

Ministry of Transportation and Utilities, who sponsored the production of these proceedings.

Our many thanks to our loyal members who attended, many of whom presented interesting and informative papers; to the exhibitors; and to our American Wind Energy Association (AWEA) colleagues who visited us.

PROCEEDINGS AVAILABLE FROM:

The Canadian Wind Energy Association (CanWEA)
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OTTAWA, Ontario
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CANADIAN WIND ENERGY ASSOCIATION
THIRD ANNUAL WIND ENERGY CONFERENCE

PROCEEDINGS

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THE CANADIAN WIND ENERGY ASSOCIATION

CANADIAN
WIND ENERGY
ASSOCIATION

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

INTRODUCTION

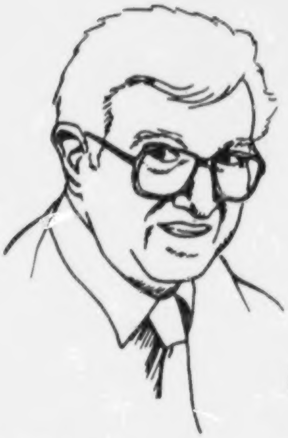
The growing interest in wind energy in Canada was demonstrated by the record attendance and interest in this third annual Canadian Wind Energy Association Conference.

In addition to the continued support of the technical community and the general support of the public, the attendance of business leaders and entrepreneurs has illustrated the accelerating interest in wind energy as a commercial enterprise.

We look forward to the continued support for both the association and this annual conference which, with each year, is helping to bring together more and more people interested in the advancement of this energy source.

Vincent P. Lacey

Vincent P. Lacey
President 1987

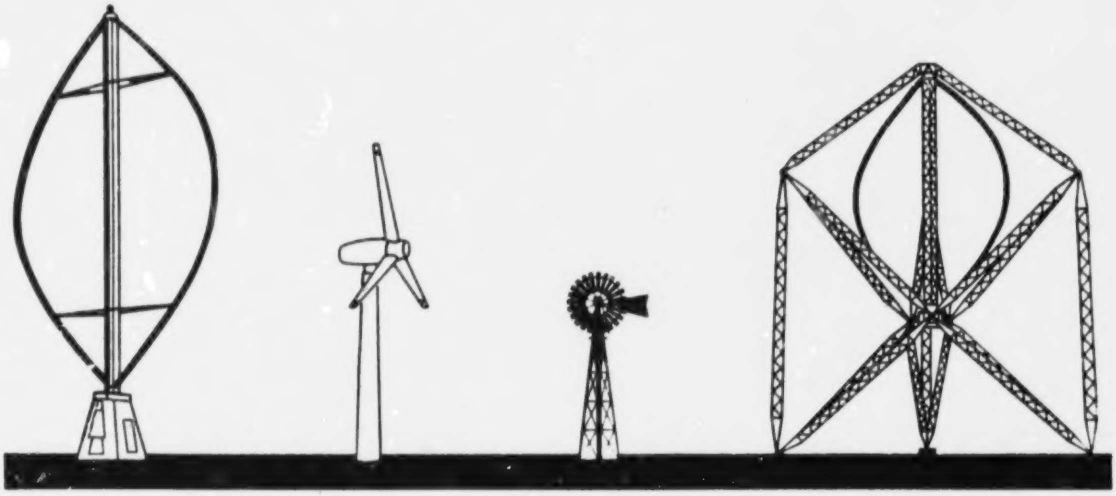


The
R. J. TEMPLIN
AWARD

For outstanding contributions
to the development of
Canadian wind energy technology

To

A.E. Sinnott



Presented by:

The Canadian Wind Energy Association
3rd Annual Conference, Calgary, Alberta
September 27-30, 1987

WIND RESOURCE ASSESSMENT

Electric Utility Planning Council

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The availability of wind resources to meet Alberta's electric demand.

In May, 1986, the Alternate Energy Resources and Technologies Committee (AERT) of the Electric Utility Planning Council of Alberta commissioned DRB Engineering Consultants Ltd. to examine what contribution wind turbines distributed throughout Alberta could make to the supply of electric demand in the province.

DRB Engineering Consultants Ltd. obtained sixteen years of hourly wind speed records, collected by Atmospheric Environment Service, a division of Environment Canada, for ten locations distributed throughout Alberta. These records were placed into computer models specifically developed to simulate the real time operation of wind turbines distributed throughout the province.

Study objective

The objective of the study was to determine what contribution wind turbines could make to the supply of Alberta electric demand. Specifically, the following three questions were identified and analyzed in this study:

1) What areas of the province have the greatest wind potential?

2) Would power be available from distributed wind turbines at times of peak electrical demand?

3) How would distributing wind turbines throughout Alberta affect the availability of electricity produced from wind?

Study findings

The following observations can be made from this study:

1) The best sites for wind turbines are concentrated in southern Alberta.

2) During times of peak electrical demand, the average potential capacity factor of wind turbines distributed in southern Alberta is approximately 27 percent.

3) Distributing the siting of wind turbines would make the total electric power generation from the wind resource more predictable.

Study findings

The best sites for wind turbines are concentrated in southern Alberta.

Southern Alberta exhibits the greatest wind energy potential. Wind turbines located in southern Alberta would experience higher operating time and produce more energy per kilowatt of installed capacity than wind turbines located in central or northern Alberta.

The values shown in Figure 1 and Figure 2 are indicative of the wind resource in the province. These values assume 100% availability of the wind turbine. Maintenance or repairs to the wind turbine would result in lower values of capacity factor and operating time at all sites.

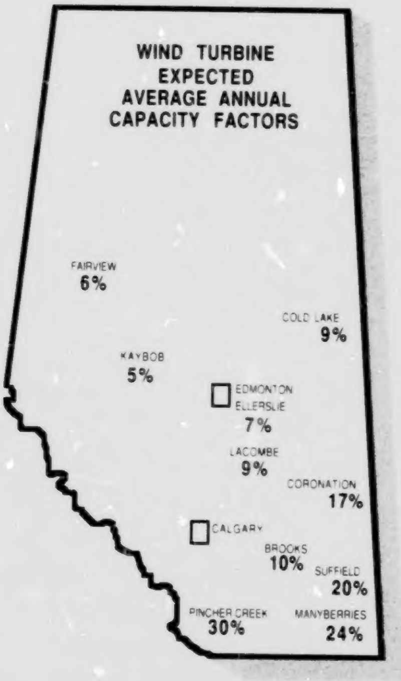
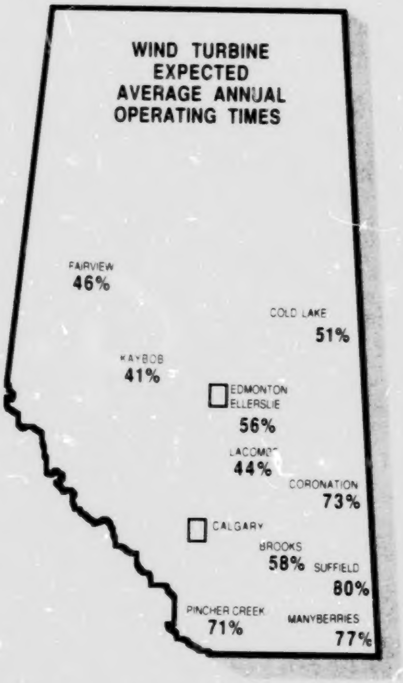

WIND TURBINE
EXPECTED
AVERAGE ANNUAL
CAPACITY FACTORS
FAIRVIEW
6%
COLD LAKE
9%
KAYBOB
5%
EDMONTON
ELLERSLIE
7%
LACOMBE
9%
CORONATION
17%
CALGARY
BROOKS
10%
SUFFIELD
20%
PINCHER CREEK
30%
MANYBERRIES
24%

Figure 1 Wind turbines installed in southern Alberta would produce more energy per kilowatt of installed capacity than wind turbines installed in central or northern Alberta.


WIND TURBINE
EXPECTED
AVERAGE ANNUAL
OPERATING TIMES
FAIRVIEW
46%
COLD LAKE
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KAYBOB
41%
EDMONTON
ELLERSLIE
56%
LACOMBE
44%
CORONATION
73%
CALGARY
BROOKS
58%
SUFFIELD
80%
PINCHER CREEK
71%
MANYBERRIES
77%

Figure 2 Wind turbines installed in southern Alberta would have sufficient wind speeds available to operate more often than wind turbines installed in central or northern Alberta.

During times of peak electrical demand, the average potential capacity factor of wind turbines distributed in southern Alberta is approximately 27 percent.

The electric power requirements of customers vary from season to season as well as day to day and hour to hour. For example, customer electric demand is significantly greater during the day than at night.

Electric utilities must ensure that enough capacity is available to continuously meet customer electric demand. Generating capacity is generally constructed to meet peak electrical demand. Therefore, the value of supply sources including wind power are greatest if they can generate power during periods of peak customer electrical demand.

The following observations were made regarding the relationship between customer electric demand and the expected capacity factor of wind turbines distributed in southern Alberta (see Figure 3):

1) The average expected capacity factor would be approximately 27 percent during times of peak customer electric demand throughout the year.

2) In winter, the expected capacity factor would be lower during peak electrical demand hours than during the other hours.

3) In summer, the expected capacity factor would be higher during peak electrical demand hours than during the other hours.

Wind turbines distributed province-wide would show the same capacity factor pattern, with an expected average capacity factor near peak customer electric demand of 19 percent.

Distributing the siting of wind turbines would make the total electric power generation from the wind resource more predictable.

Installing wind turbines in multiple locations will improve the predictability of the total electric production from the wind turbines. Wind velocity varies from location to location, and the study shows that while the wind is not blowing at one location there is a high probability that it will be blowing at another.

One indicator of how the predictability of the wind resource would increase by distributing wind turbines is reflected in the available operating time of distributed wind turbines. The average available operating time of single wind turbines at the three sites studied in southern Alberta is 76 percent. Taken as a group, the available operating time for the same three sites is 97 percent. The improvement in operating time, amount of time that at least some wind power could be generated, results from wind power often being available at one site while not at another.

The results show that the total power output of distributed wind turbines becomes more predictable as the number of sites increases and approaches the long term average power output for that region and time period. For example, as the number of sites in southern Alberta increases, the total wind power output during the winter period would approach 25 percent for the peak load hours of the day, and 29 percent for the remaining hours of the day, as shown in figure 3.

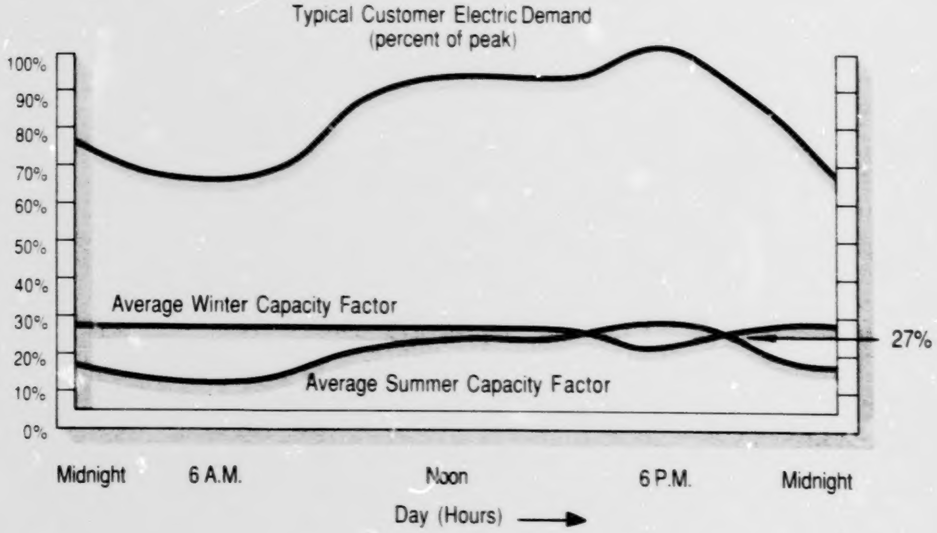


Figure 3 During times of peak electrical demand, the average capacity factor of wind turbines distributed in southern Alberta is approximately 27 percent.

Background

Method

Based on the availability of data, AERT selected ten sites distributed throughout Alberta for the study. At each of the sites, sixteen years of hourly wind speed records collected by the Atmospheric Environment Service, a division of Environment Canada, were placed into computer models developed by DRB Engineering Consultants Ltd. These computer models simulated the simultaneous operation of a Nordtank NTK 65/13S wind turbine at each of the sites and compared the power output of the wind turbines to the province's historical electric demand on an hour by hour basis.

Multiple site simulations were studied to identify the effects of distributing wind turbines. Two scenarios were studied; three and seven site simultaneous operation. The three sites were chosen to represent wind turbines distributed in southern Alberta. This model simulated the simultaneous operation of wind turbines located at Pincher Creek, Suffield and Manyberries. The seven sites modeled the simultaneous operation of wind turbines located at Pincher Creek, Suffield, Manyberries, Lacombe, Cold Lake, Fairview and Coronation, and was chosen to represent wind turbines distributed province-wide.

For the purpose of this study, the year was divided into three time periods: 1) the winter period, November to February, 2) the spring/fall period, March, April, September and October, and 3) the summer period, May to August.

The study results show agreement with actual data collected at Pincher Creek.

The study results show good agreement with actual data collected by TransAlta Utilities Corporation at two Pincher Creek sites. An analysis of data collected between 1985 and 1986 at W. Schauerte's 5 kW and E. Sinnott's 40 kW Enertech wind turbines located at Pincher Creek, show average seasonal capacity factors of 41, 17 and 30 percent for the winter, summer and spring/fall periods respectively. These results are comparable to the long term seasonal capacity factors predicted in this study of 38, 22 and 29 percent for the winter, summer and spring/fall periods respectively.

Requests for additional information.

If you would like a copy of the full report or if you have any other questions concerning the study, please contact Mr. Dwayne Bateson at the following address:

Mr. G.D. Bateson
Alternate Energy Resources Technologies Committee, Member
c/o TransAlta Utilities Corporation
Box 1900
Room T1-903
Calgary, Alberta
T2P 2M1
Tel: (403) 267-7129.

Glossary

Capacity Factor (%)	Energy output of a wind turbine expressed as a percentage of the wind turbine's nameplate rating times total hours available.
Operating Time (%)	Amount of time where sufficient wind speed exists to operate a wind turbine, expressed as a percentage of the total hours available.

WIND ENERGY IN ALBERTA: AVAILABILITY AND RELIABILITY

Mary-Ellen Jones, P.Eng.
Small Power Producers Association of Alberta

AVAILABILITY OF THE RESOURCE

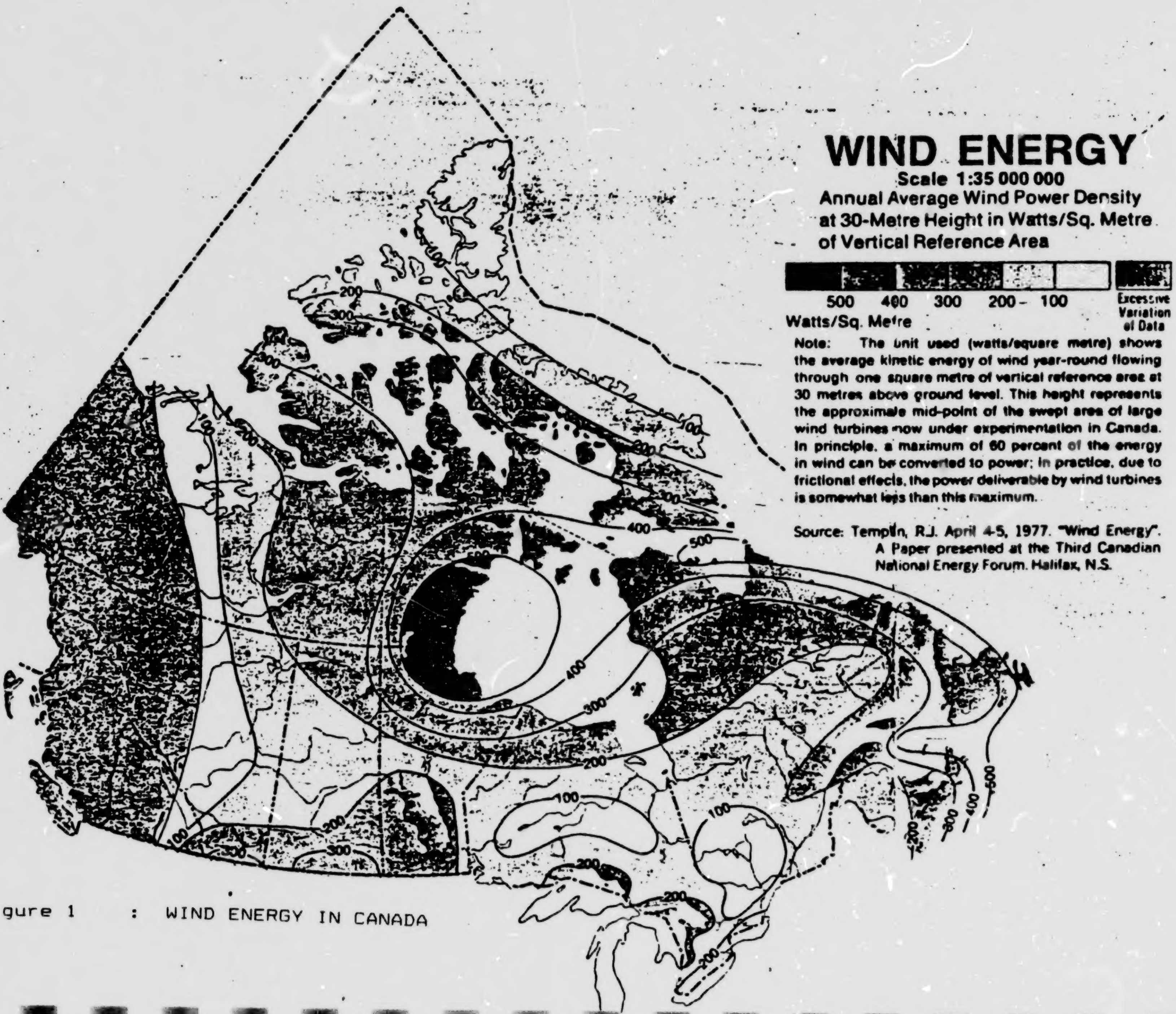
The ultimate recoverable potential for wind in Alberta is enormous.[1.] Average annual wind speeds are highest in the southern part of the province as can be seen in Figure 1. The Lethbridge area experiences wind speeds that are as high as any in Canada apart from the eastern coastal region, while central Alberta can be regarded as having average wind speeds.[2.] This gives a general indication of the wind speed in each area but wind energy tends to be very site specific depending on local topography and other factors. There may be specific sites in central Alberta that have higher winds than indicated and the reverse is true in the Lethbridge area.

In Alberta during all seasons, wind energy exhibits a diurnal trend with higher wind speeds occurring during the mid-afternoon and lower wind speeds during the early morning hours.[3.] An example of this is the "Hourly Wind Power" for Calgary that was produced from Atmospheric Environment Service (AES) data (Figure 2)[4.] Generally, in southern Alberta the wind speeds increase just before noon and start to subside in the evening.

Winds in Alberta also exhibit seasonal trends. The winter months, in general, have higher average wind speeds.[5.] Long-term wind data from AES shows that most sites' average monthly wind speeds peak between October and January. High winds coinciding with colder temperatures produces more power than less dense summer winds.

All studies of wind in Alberta have used the long term data that has been collected by AES. There are limitations to using AES airport or horticultural data for estimating and predicting Wind Energy Conversion Systems (WECS) operations and performance. Wind speed data has been collected at various heights. In Southern Alberta, for example, Pincher Creek data has been collected at the 8.8 metre height, Suffield data at the 9.1 metre height while Lethbridge and Manyberries have been at the standard height of 10.1 metres. Long term data at WECS hub height is not available so the AES data must be scaled up to estimate the potential WECS wind speed.

Airports are generally located in the least windiest location in an area. Long term data collected at airports is thus biased. Estimates using airport data will be conservative in nature. Siting of WECS by using airport data has given poor



WIND ENERGY

Scale 1:35 000 000

Annual Average Wind Power Density at 30-Metre Height in Watts/Sq. Metre of Vertical Reference Area

Note: The unit used (watts/square metre) shows the average kinetic energy of wind year-round flowing through one square metre of vertical reference area at 30 metres above ground level. This height represents the approximate mid-point of the swept area of large wind turbines now under experimentation in Canada. In principle, a maximum of 60 percent of the energy in wind can be converted to power; in practice, due to frictional effects, the power deliverable by wind turbines is somewhat less than this maximum.

Source: Templin, R.J. April 4-5, 1977. "Wind Energy". A Paper presented at the Third Canadian National Energy Forum. Halifax, N.S.

Figure 1 : WIND ENERGY IN CANADA

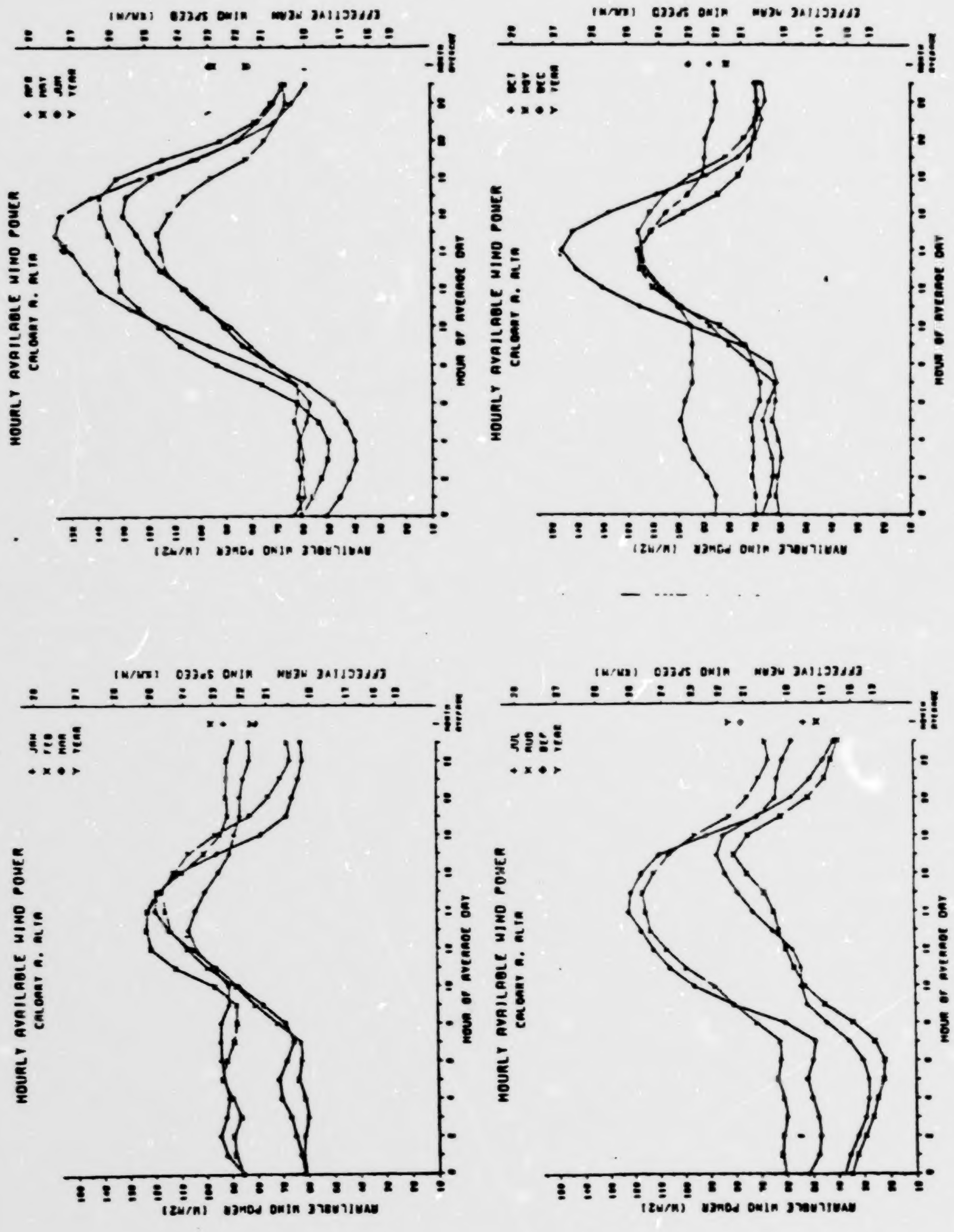


Figure 2 : HOURLY AVAILABLE WIND POWER IN CALGARY, ALTA.

results in California as well as in other parts of the world. Hub height collection of wind speed at the site gives a much better indication of the potential of the wind resource. This is especially true in rolling terrain.

In Alberta there is a need for wind prospecting. Wind speeds need to be collected at hub height and more sites are needed in the high wind area in Southern Alberta. This collection should be started before the development of WECS installations but will probably be collected once a market for the sale of power has been achieved. Wind energy development should not be postponed until this data is collected but developments that understand the limitations of the AES data and the need of hub height site data will be able to make better siting decisions.

Reliability_of_the_Resource

Although wind in Alberta has both diurnal and seasonal trends, wind intensity varies between sites at any instance in time. Periods of high and low wind do not usually occur simultaneously at all sites.[6]. Secondly, periods of calm at all sites approaches zero percent as the number of sites increases. Also, maximum and average duration of calms tend to decrease with increasing annual wind speeds.[7]. All of this adds to a time smoothing of the power available to the system as a whole and in effect, makes the power contribution from wind a much more reliable source.[8].

To estimate the energy potential of wind power producers in Alberta, assumptions have to be made about the placement, efficiency, average wind density and number of machines. The technical potential is best estimated in a study by Robinson (1984). He assumed that 600,000 wind machines erected on a one kilometre grid over all improved land in Alberta, with an average machine efficiency of 27%, would tap an average wind density of 300 watts per square metre (W/m^2).[9]. If an efficiency of 30-35 % was used, about 500,000 machines would be needed for the same production. Either arrangement would produce 135,000 petajoules (37,500,000 GWh) per year.

For Alberta, a study commissioned by Energy, Mines and Resources in 1981 estimated a 300 MW "realizable potential" by the year 2000.[10]. This study incorporated economic as well as market factors to reach it's conclusions. If these factors change positively towards wind energy then the 300 MW would be a conservative estimate of the installed capacity in Alberta by the year 2000. A capacity of 600 MW in Alberta could be assumed as a rough estimate for the year 2000 if positive changes occur in the economics of private power.

Notes

[1] David Brooks, Herman Boerma and William Ross, Conservation and Renewables for Energy Requirements in Alberta 1985 - 2010, Prepared for Proceeding No. 850129 of the Energy Resources Conservation Board (n.p.: n.p, 1985), p. 97.

[2] Alberta Energy and Natural Resources, Prospects for Solar and Wind Energy Utilization in Alberta, by Dr. E.J. Wiggins, ENR Report No. 89 (n.p.: n.p., 1978), p. 3.

[3] Alberta Energy and Natural Resources, Prospects for Solar and Wind Energy Utilization in Alberta, p. 20.

[4] D.G. Howell, Processing of Alberta Wind Data and its Application to Wind Energy System Design, Solar and Wind Energy Research Program, (n.p.: n.p., 1982), p.9.

[5] Alberta Energy and Natural Resources, Prospects for Solar and Wind Energy Utilization in Alberta, p. 18.

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[7] International Energy Agency, Wind Energy - An Assessment of the Technical and Economic Potential, A Case Study for the Federal Republic of Germany, (n.p: n.p., 1981) p. 44

[8] World Meteorological Organization, Meteorological Aspects of the Utilization of Wind as an Energy Source, Technical Note No. 175 (Geneva: World Meteorological Organization, 1981) p. 129.

[9] David Brooks, Herman Boerma and William Ross, p. 97.

[10] Science Council of Canada, Renewable Energy: Innovation in Action, by Jeff Passmore and Ray Jackson (Ottawa: Minister of Supply and Services, 1984), p. 13.

DEMONSTRATION PROJECTS

CANADIAN WIND ENERGY ASSOCIATION
1987 Annual meeting,
Calgary, Alta
27-30 september 1987

Status of the Wind/diesel Coupling: Activities at Hydro-Québec

R. Reid B. Saulnier A.O. Barry A. Drolet B. Dubé
M. Lavallée L. Martell
Hydro-Québec

SUMMARY

The paper describes briefly the technico-economic background leading to the Wind/diesel coupling as a means of reducing the high annual operating deficit of remote power systems.

With the no-storage high penetration scenario, at optimum penetration with the reference case for the average wind speed expected in Northern Quebec, 54 % of the fuel used to produce electricity can be displaced by wind energy. For some of these communities with better than average winds, up to 75 % of the fuel currently spent to produce electricity can be displaced. In addition, a substantial quantity of fuel used for space and/or water heating will be displaced.

A program schedule for the implementation of such wind/diesel systems in HQ's remote networks is presented and discussed.

Results on the achievements of the first two phases of this program are given; they cover the demonstration project of Kuujjuaq in the Ungava Bay and the development and implementation of the no-storage high-penetration Wind/diesel scenario at the experimental WECS testing facility of HQ.

The main goal of the Kuujjuaq's project is to demonstrate the technical feasibility of the installation of a 65 kW wind turbine in harsh environment typical of northern diesel-electric network.

The objective of the second phase of this program is to develop a regulation and control system that will allow wind turbines to supply all of the demand of the community, when sufficient wind is available, the diesel being shutdown, while maintaining and/or improving the quality of power .

The paper will present some preliminary analytical results demonstrating the transient response and stability of the high penetration no storage wind/diesel scenario. These results are based on real parameter values of IREQ's experimental setup (Darrieus wind turbine, diesel genset, simulated community,and controlled heating load) that will be used for the validation of the simulation model for the proposed scheme.

Keywords: Wind/diesel, high-penetration, economics, regulation and control strategies, simulation, system stability

• 1 Introduction

Due to the unpredictable nature of the wind, the utilisation of wind turbines as generating units in existing electrical power systems raises numerous questions as to their potential as a viable and economic adjunct to conventional electric power sources. Hydro-Quebec has been involved in research and development work in wind energy since 1975 Through research activities, many aspects of this technology have been looked at on both theoretical and experimental basis. A constant concern in this activity has been to improve the understanding of these complex machines so as to allow their economical integration in existing networks. It is now well recognized that their economic potential will first be demonstrated in remote networks where electricity production costs and wind regimes are high

Hydro-Québec, by its expertise and its ready access to the utility and its network is in a good position to ensure the success of this undertaking.

• 2 Historical : Projects Background

A brief overview of the wind energy activities carried at Hydro-Québec research institute since the inception of this program will put in perspective HQ's increased involvement in W/D coupling.

•40 kW horizontal axis with synchronous generator.

Initiated in 1975, this project aimed at the demonstration of the technical feasibility of a WECS used in a compressed-air-storage scheme. The resulting system was intended to be used as a fuel saver in conjunction with gas turbine in Magdalen Islands where salt domes could be used as compressed air reservoirs.This research resulted in the demonstration that a load-controlled WECS driving a synchronous generator can be operated in a stand-alone mode[1].

• Magdalen Islands 230-kW wind turbine

In 1977,Hydro-Quebec, jointly with the National Research Council, installed a 230 kW Darrieus wind turbine in Magdalen Islands. The machine was equipped with an asynchronous electrical machine and connected via transformer to the local 13.2 kV network. The objectives of the project was to demonstrate the reliability of this type of turbine in a remote network in harsh environmental conditions. The machine was installed in a low-penetration no-storage fuel saving mode.The test program resulted in the gathering of valuable data on the performance of the turbine over a period of 5 years [2,3] (effect of icing on performance, effect of network frequency variations on power output transient of the wind turbine, etc..)

• Aerogenerator testing facility in Varennes.

The experience gained at M.I. was instrumental in the planning of the aerogenerator testing facility presently operational on IREQ's grounds .The characteristics of the laboratory has been described in earlier publications [4]. It has resulted in essential experimental data on WECS torque during electrical transient, guy wire dynamics, modal analysis of rotor and variable-speed SFC drive system analysis. A model for predicting wound-rotor asynchronous machine linked to the network via a static frequency converter was validated. This model[5] takes into account aerodynamic, mechanical and electrical characteristics of the overall system.

For the next three years, this laboratory will be used for the development of a regulation and control system adapted to the high-penetration-no-storage wind/diesel scenario.

• 3 JUSTIFICATION FOR WIND/DIESEL IMPLEMENTATION

Approximately 800 remote diesel generator units supply electricity to 290 communities in Canada. The total installed capacity amounts to 350 MW with an average utilization factor of 17.3 %. Electrical production costs are typically much higher in these communities than anywhere else in the main southern canadian network. In general, the wind regime is better than in the south. It is recognised that wind turbines will find their first economically viable applications in this type of environment.

Cost effectiveness and power supply quality are the two basic requirements for an effective integration of WECS in any given community. In that sense, we are looking for control strategies that will ensure that a maximum amount of the energy produced by the WECS serve useful purposes in the community (primarily electricity generation with the surplus used for heating buildings and/or water).

• 3.1 W/D coupling : technical Background

The integration of WECS in a given community power system must take into account the characteristics of the major equipments involved, a few of which are given below:

- Demand and WECS power output are both random. However, demand, being largely fashioned by community habits, follows more predictable patterns.
- diesel generating plant has good load following capability but is an inefficient fuel to electrical energy converter. Also, as its load decreases, its specific fuel consumption increases. Operating and maintenance costs are high.
- WECS is a poor power producer, due to the random nature of wind. However, on a yearly basis, it is an excellent energy producer. Reliable machines exist today that have very low Operating and Maintenance costs. For a given wind generator installed capacity, a group of machines will exhibit smoother power output than a single machine.
- Mismatch between wind and demand imposes increased load following burden on the diesel generating set. The net demand, as seen by the diesel is more random than the demand itself.
- Power and frequency stability call for a variable dump load for maintaining the energy balance in the system.

A detailed analysis of current operating practices of the all-diesel generating plant and their effect on the planning of a large penetration of WECS into this network must also be taken into consideration for efficient W/D coupling and optimum economic penetration. Simulation programs that facilitate these choices, both in transient and in steady-state conditions, need to be developed.

• 3.2 W/D coupling :Economic justification

As discussed in a previous paper[6], the most cost effective power production system in

Northern Quebec communities is the no-storage, high penetration wind/diesel scenario.

An economic analysis based on this scenario was carried.The analysis assumes that the control and regulation system will allow wind energy to be used primarily to supply the electrical demand at a value equal to the cost of fuel for the diesel generator set, while the surplus is used to supply part of the heating demand of the village at a value equal to the cost of fuel used for heating.

Before such a project is implemented, much more detailed calculations are needed. Each community will have to be considered separately for the choice of sites (wind regime), cost of fuel and electricity demand. Wind energy will be more profitable for those communities were the fuel is supplied by the COOP (higher fuel prices). Figure 5 and 6 show that the optimum penetration for those COOP communities is 100 % for a wind speed of 6.8 m/s and 200 % for a wind speed of 7.8 m/s.

The financing aspect also deserves special attention. For example, even if Hydro-Quebec does not pay income taxes, advantage can be taken of the accelerated depreciation through Lease-Purchase (LP), the lessor absorbing the tax credits and leasing the installation to Hydro-Quebec. Figures 5 and 6 are showing this effect on the reference scenario and for COOP communities. For this latter case, the optimum penetration becomes 150 % and more than 300 % for wind speeds of 6.8 and 7.8 m/s respectively.

The calculations were based on a typical 65 kW danish wind turbine. Recent developments tend to show that slightly larger wind turbines are more cost effective. For communities were the fuel cost, the winds and the electricity demand dictate a high wind turbine installed capacity, larger wind turbines might be a better choice, provided that enough turbines are installed for a given community to result in a relatively stable wind power.

Figure 2 shows that for the optimum penetration with the reference case for wind speeds of 6.8 and 7.8 m/s respectively, 54 % and 63 % of the fuel used to produce electricity can be displaced by wind energy. For the COOP lease-purchase case with a wind speed of 7.8 m/s, the portion of the electrical demand that would be suplied (or the fuel displaced) by wind energy climbs to over 76 %.

The Northern Quebec wind energy potential for the reference case and for the average wind speed of 6.8 m/s at the optimum penetration (100 %), calculated from reference 6, would be around 9 MW of wind turbines for a NPV of around 8 000 000 $.

• 3.3 WIND/DIESEL PROGRAM OBJECTIVES

Hydro-Quebec objectives for implementing the W/D scenario in its remote networks are the following:

- To develop a reliable Wind/diesel coupling system which will allow the optimal reduction of operating costs in remote networks.More specifically,the program aims at designing and developing a control and regulation system which will permit WECS to be coupled to diesel generator sets in such a way that:

-The penetration level (defined as the ratio of installed WECS power capacity to peak power demand of the local network) will be determined by economic criteria and not by current operational constraints which limit WECS contribution into diesel based network to a low percentage of the total diesel capacity.

-WECS always has production priority to the extent that if wind power output is sufficient to feed the demand, the diesel can be shut off.

The design that we intend to develop at Hydro-Quebec stems from demonstration of W/D coupling made in 1977 by WTG on Cuttyhunk Island. This installation showed that, when the wind was strong enough, the diesel gensets could be shutt off and the demand supplied by wind power alone. Likewise, the results obtained in 1978 at IREQ on an horizontal axis wind turbine driving a synchronous generator will be useful to reach the objectives of the proposed project. The system was operated in an autonomous mode with a speed regulation loop that acted directly on the load. More recently at ECN,in Holland, this scheme has been put in operation.

The commercial impact of the wind diesel coupling technology is highly promising . It could lead to the development of a Canadian manufacturing plant in joint venture with a recognized WECS producer. This project has the potential of starting a manufacturing activity of approximately 80 M$, only for the Québec market (principally 12 M$ for Ungava, 18 M$ for Lower North Shore of St-Lawrence River, 36 M$ for Magdalen Islands).

• 4 GLOBAL SCHEDULE OF WIND/DIESEL COUPLING IMPLEMENTATION

To give some perspective towards the implementation of this Wind/diesel scenario in Quebec, Figure 7 gives a tentative schedule of the development and demonstration activities.

This global program covers a period of 9 years, including the Kuujjuaq WECS demonstration project presently under progress.The schedule present an overview of the different phases that will lead to the full development of the W/D potential in Ungava region.

• 4.1 PHASE 1 KUUJJUAQ'S DEMONSTRATION PROJECT

The main goal of the Kuujjuaq's demonstration project is to demonstrate the technical feasibility of the installation of a 65 kW wind turbine in a diesel-electric network as a fuel saver and to diversify the methods of energy production for remote networks.

Kuujjuaq was choosen for this demonstration project because it is easily accessible (daily flights from Montreal) and because it is the northern headquarter of Hydro-Quebec. Figure 8 shows the location of Kuujjuaq and of the other northern communities.

• 4.1.1 SITE SELECTION

After discussions with the local community and with due consideration to the proximity of the local network a site was choosen. A 10 m anemometer tower was installed in October 1985 to verify the wind regime at the site.

Preliminary analysis of the data shows that the average wind speed is 20 % higher at the selected site than at the airport. Analysis of past records showed that wind speed decreases with a decrease in temperature.

• 4.1.2 ENGINEERING

Detailed engineering was done by Hydro-Quebec for the foundations, the lifting equipment and for the connection to the network. The modifications to the wind turbine required by Hydro-Quebec were engineered by the manufacturer.

A test program to determine the impact of the wind turbine on telecommunications at the airport was prepared by Transport Canada in cooperation with Hydro-Quebec. The tests were done with a Transport Canada airplane on October 24, 1986 for the first commissionning tests of the wind turbine. No interference was found.

• 4.1.3 SELECTION AND INSTALLATION

The wind turbine was selected in February 1986 and specifications were written. The contract was signed with Danregn Vindkraft A/S (Bonus) on April 21, 1986. After factory tests, shipping to Montreal was approved by Hydro-Quebec in July. The foundations were poured and the turbine was assembled and erected without the use of a crane in September and October. The commissionning tests were started on October 24 and on November13, the machine was transfered to Operations. The data transmission line between the wind turbine and the diesel power plant was installed in February 1987, we then installed a data acquisition and transmission system.

• 4.1.4 DATA ACQUISITION AND TRANSMISSION SYSTEM

The data acquisition system used for the communication with the wind turbine is divided in three groups of instruments depending on their location. Figure 9 shows the general layout of the system. The system also allows starting or stopping the wind turbine from the diesel power plant, about 2 kilometers from the turbine.

The wind turbine purchased included a microcomputer and a modem for communications. A TRS-102 microcomputer was installed at the diesel power plant to manage the communication system and collect daily data. It communicates, via modems, with the wind turbine and with IREQ in Varennes, 1600 km away, where another microcomputer stores the data received daily from Kuujjuaq.

• 4.1.5 PRELIMINARY RESULTS

Except for minor problems (system specific to the Kuujjuaq's machine), to September 8 1987, the wind turbine has been running (generating and coasting) approximately 4,200 hours supplying 47 MWh of electricity to the network.

An example of the use of the data collected at IREQ is given in figure 10 which compares the raw 5 minute averages, power vs wind, to the standard power curve. Figure 11 shows the same data regrouped in 1 m/s bins. Both curves show that the turbine produces more power than expected. This could be attributed to a combination of factors: data not corrected for temperature nor for altitude and possible slight blade pitch deviation.

The other form under which data is collected at IREQ is shown in Annex 1. The data string, as stored by the turbine microcomputer, is read by the TRS-102 in the diesel power plant and transmitted at IREQ. Annex 1 shows the data string and its interpretation. The energy, running time, etc..., are read from totalizers.

• 4.2 PHASE 2 W/D CONTROL SYSTEM DEVELOPMENT

The installation of equipments in remote northern areas of Canada is always very expensive due to the high transportation costs and the investments in support logistic required. Obviously, the development of a such a system in these area would be prohibitive both in terms of time and money.

We propose to develop this system at IREQ where the technical resources and the scientific expertise are available. Once the system is developed and its reliability demonstrated, implementation of the technology in remote networks will be possible with the best chances of success. Figure 12 presents the planned schedule of activities for phase 2 of the project.

• 4.2.1 HIGH-PENETRATION NO-STORAGE W/D COUPLING

The Wind/diesel system that we propose to develop will be designed and built according to the following strategy :

- Priority is given to WECS production.
- diesel gensets are the standby units; if the WECS output can safely meet the load,diesels are shut off.
- Dissipative loads installed in community buildings are used for absorbing the difference between the demand and the WECS + DIESEL power output. Dissipative loads could be of two types: variable by step(operated by addressable frequency sensitive switches) and/or infinitely variable (thyristor controlled) loads.
- The reference frequency of the regulation could come from an oscillator, the controlled parameter being the network frequency.
- The control system monitors the power consumed by the dissipative loads. If the level of power consumption reaches a predetermined low level setpoint,the control system commands the startup of one WECS or diesel genset . At the opposite, when a predetermined high level setpoint is reached, then one diesel or one WECS is closed.
- When the demand is met by the WECS only, the synchronous generator(s) of the diesel group(s) provides the reactive power to the asynchronous generator of the WECS.
- When the diesel is operating, it could provide the frequency reference of the network. It could also be operated at a fixed power production level, while the control system maintains the grid frequency.

It is planned to extend the monitoring program of the KUUJJUAQ demonstration project to incorporate data from the network, demand load profile from the community as well as better wind and atmospheric data. This data will allow a better simulation of the load.

We will develop the system through interactive analytical and experimental phases . This approach has been used successfully at IREQ for validating WECS related to analytical models that are well recognized through the scientific community today (aerodynamics,structural dynamics, electro-mechanical and transient models).

When the model will have been fully validated by experimental work, the sensitivity studies for different systems will be done.

This approach insures the greatest return on investment for R&D work. Once the program is completed, the model will provide a valuable tool for sensitivity analysis of the proposed scenario for other W/D combination . This will minimize the margin of error for the design of regulation and control systems. Matching W/D equipments of different characteristics in any remote location,will be an easier task, thus ensuring a successful and cost effective application of wind/diesel systems in remote networks.

• 4.2.2 ANALYTICAL WORK

The electro-mechanical transient model of the 50 kW Darrieus WECS of IREQ has already been validated in previous work dealing with the modelisation of a wind turbine driving a wound rotor asynchronous electrical machine connected to the network via a Static Frequency Converter[5,7,8] . In this project, the dynamic characteristics of the wind turbine and the regulation system of the variable speed drive were determined. Only part of this model will be used since the experimental WECS will be connected to a squirrel cage induction generator. Models of diesel genset that were developed for studying power system stability on a large network will be used.

The schematic of the regulation loops for all these elements is presented in figure 13 . So far, we have identified the transfer function of these two units working together with a dissipative load (acting as a buffer) to satisfy a varying demand with variable wind power. The overall transfer function of the system representing the effect of a step variation in demand power ($\Delta P_{\mathbf{dem.}}$) on the network frequency deviation ($\Delta\omega_{\mathbf{nw}}$) defines a third order system of the following form :

$$\Delta\omega_{\mathbf{nw}} / \Delta P_{\mathbf{dem.}} = - [(K_{\mathbf{aero}} + K_{\mathbf{el.}}) S + 2 H_{\mathbf{wecs}} S^2] / (A S^3 + B S^2 + C S + D)$$

where S is the Laplace's variable and A, B, C, D are functions of the mechanical inertias of the **wecs** and the **diesel** ($H_{\mathbf{wecs}}$ and $H_{\mathbf{diesel}}$), the overall proportional and integral gain of the regulators (respectively noted by $K_{\mathbf{p}}$ and $K_{\mathbf{I}}$ on Figure 14), $K_{\mathbf{aero}}$, the proportionality factor between aerodynamic torque variation and a mechanical speed variation and $K_{\mathbf{el.}}$, the proportionality factor transforming a slip variation into an electrical torque variation.

This simplified model assumes that the mechanical speed of the WECS-induction generator behaves as a first order system in relation to the network frequency. In that case, the electrical torque becomes a direct measure of the power available at the stator of the induction generator. All energy losses caused by friction and ventilation, induction and hysteresis effects are neglected. Also, the model does not take into account the aerodynamic torque variations that are characteristic of a vertical axis WECS over one revolution. The frequency-voltage relation is assumed to be linear and the model takes into account the variations in power demand resulting from voltage fluctuation.

For the known dynamic parameters of the experimental system, we have analysed the stability of this function to a 1 pu step variation in the power demand. Figure 14 presents some results of this analysis and demonstrate that this system is stable for a large range of $K_{\mathbf{p}}$ and $K_{\mathbf{I}}$, proportional and integral gain values. From this figure, it can be seen that the maximum frequency deviation (.045 pu) happens at between 1 to 2 seconds after the step function has been triggered. After 10 seconds, this deviation has dropped to .02 pu. In other words, a .2 pu power demand step variation would create a maximum frequency deviation of 0.54 Hz on a 60 Hz network.

These preliminary results will be used to specify the initial parameters of the **regulation system**. The first prototype of the complete **regulation and control system (RCS)** will then be assembled and installed on the experimental site.

In parallel with this simplified simulation model, a detailed numerical model is being developed which will include the effect of instantaneous aerodynamic torque of the vertical axis wind turbine (taking into account dynamic stall). This dynamic model will present a realistic image of the system response under normal operating conditions. The most severe case is believed to be when the WECS provides a high percentage of the load with the diesel operating at low load.

The **control system** flow diagram will be elaborated in parallel and tested for all possible states of the system. Together with the design data obtained for the regulation system, the logic diagram of the control system will then be translated into the appropriate analog/numeric-input/output equipment, components and circuits.

• 4.2.3 EXPERIMENTAL SETUP

The experimental setup will be installed at IREQ' s WECS test site and will consist of the five major following elements, typical of the intended application (Figure 15).

- **Network (village demand).** The isolated network will be simulated by a programmable resistive load adapted to represent the demand of a typical village. Monitoring of the demand of the village of Kuujjuaq will be carried out in a parallel project and will be used for that purpose.

- **WECS (asynchronous generator).** The WECS will be a 50 kW Indal Technologies Darrieus variable speed wind turbine which has been operational at our site since 1984.

- **diesel generator set(s).** The diesel genset is a 30 kW FORD/ONAN autonomous unit.

- **Dissipative loads** (filling power mismatch between diesel, WECS output and demand); The infinitely variable dissipative control load is of the same type as the one used to simulate the remote network (thyristor control). The fixed loads operated by frequency sensitive switches will be integrated later as they do not add a critical constraint on the system design at this stage of the project.

- **Regulation and control system**. Once the first prototype of the regulation and control system (RCS) will be installed and interfaced with the four other elements of the scenario, the analytical model will be used ,throughout the course of the experimental work, to refine the adjustments of the regulation parameters.

- **Status** . At the time of this presentation, the experimental setup is being completed. The diesel genset has been modified to include an overrunning clutch between the diesel motor and the synchronous generator and was also fitted with an electronic speed regulator. The resistance loads and their thyristor controllers will be delivered at the site in october, following some unexpected delays in their procurement . Electrical hookup will then be completed and the protection control system modifications carried out for a proper interfacing of the WECS and diesel generating units. The installation and programming of the microprocessor used for system management and load simulation is currently initiated.

It should be noted that the experimental setup is actually a worst case situation for the W/D high penetration scenario as it consists of only one Darrieus WECS (with its inherent torque ripple characteristics) having a power capacity larger than that of the diesel genset alone. In a true situation, it would be preferable to have many small WECS feeding the load. In this case, the ratio of peak-to-average-power contributed by the WECS would be significantly lower due to the dispersion of the machines, increasing the base wind power capacity in all conditions, improving the fuel savings and reducing the number of diesel starts/stops.

• 4.3 PHASE 3 DEVELOPMENT OF A NORTHERN WECS

This phase of the overall program is already in process with the Kuujjuaq demonstration project. The selection of materials (steels, lubricating oils, ...) was modified from the standard machine to account for the low operating temperatures encountered in Kuujjuaq. Heating systems were added for lubricating oils, control box, bearings,... .

These modifications to the standard 65 kW danish wind turbine are presently being evaluated in Kuujjuaq. The results might be applicable to other projects even if the specific choice of the wind turbine is different.

• 4.4 PHASE 4 DEMONSTRATION OF A PROTOTYPE

The demonstration of a prototype control and regulation system with one turbine and one diesel in a remote network would follow next.

A section of the network could be fed by the wind/diesel system while the rest of the network is fed by the regular diesel powerplant. Alternatively, the system could be demonstrated in a remote location on a simulated load.

• 4.5 PHASE 5 FULL SCALE DEMONSTRATION IN A VILLAGE

Once the prototype system will have been demonstrated in a remote location, a village will be retrofitted for a full scale demonstration of the high penetration no storage scenario.

This would involve the calculation of the optimum penetration level, the choice of a wind farm site, the choice of the wind turbines, the installation of dump loads in the heating systems of large community buildings. The control and regulation system will control the wind turbines, the dump loads and the diesels.

• 4.6 PHASE 6 IMPLEMENTATION

After a period of succesful operation of the system installed during phase 5, the commercial implementation of the system could be undertaken for the other remote communities were the winds and the cost of fuel makes the system economically interesting

• 5 CONCLUSION

We have shown that wind energy could have a great economic potential in remote networks with the use of the no storage high penetration scenario.

A realistic program for the orderly development and implementation of this scenario was presented.

For the long term, the national and international market potential of wind energy for remote networks could lead to an important manufacturing industry in Canada.

ACKNOWLEDGMENTS

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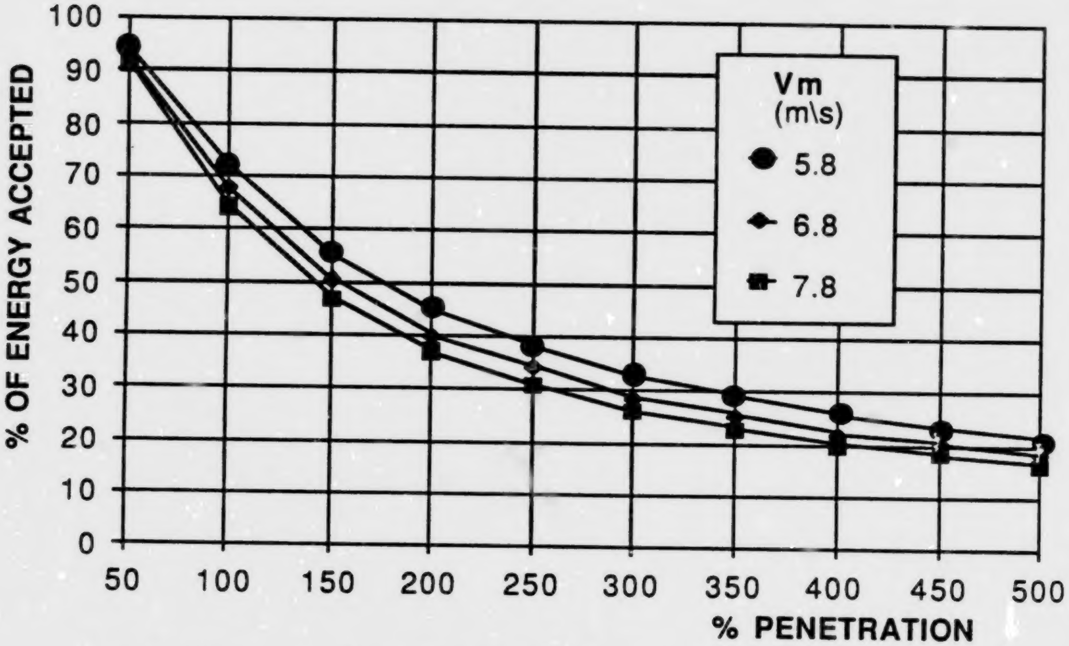


FIGURE 1 Percentage of the energy accepted by the network

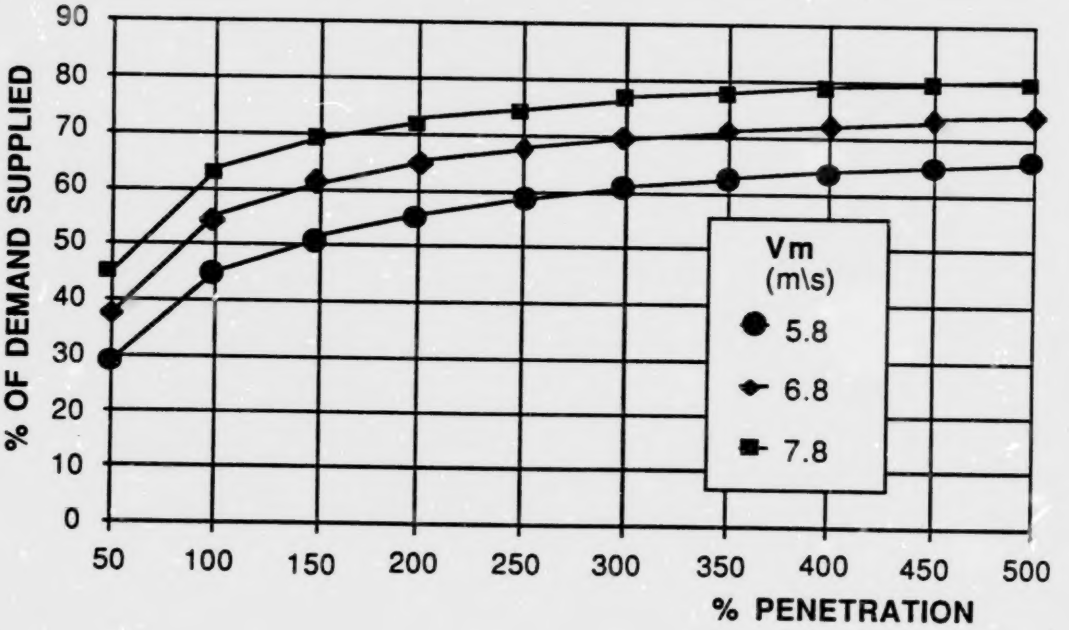


FIGURE 2 % Of Network Demand Supplied By Wind Energy

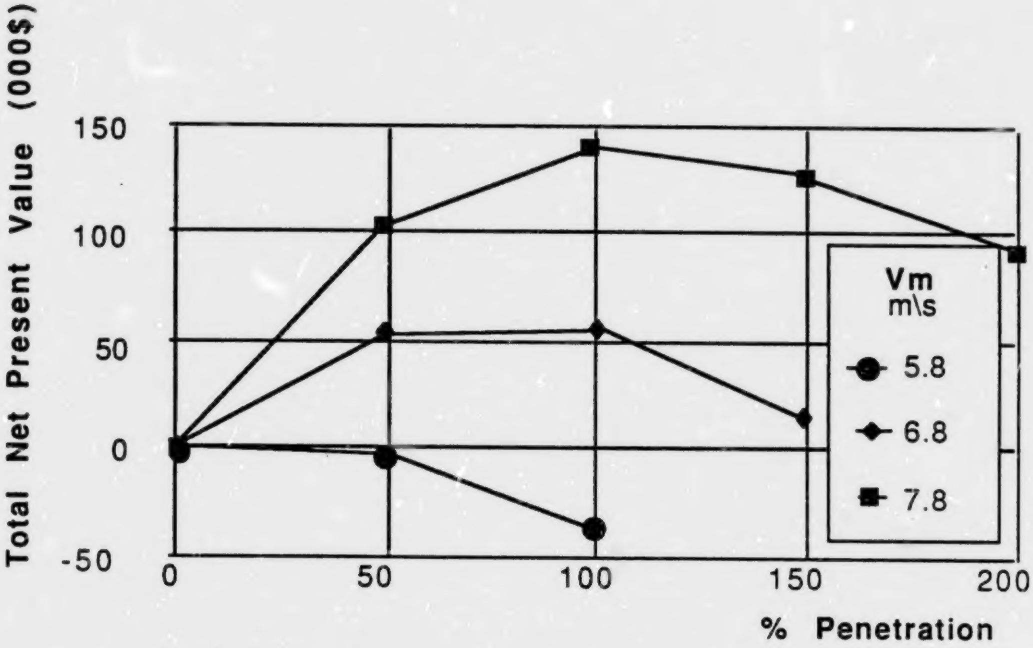


FIGURE 3 Total Net Present Value

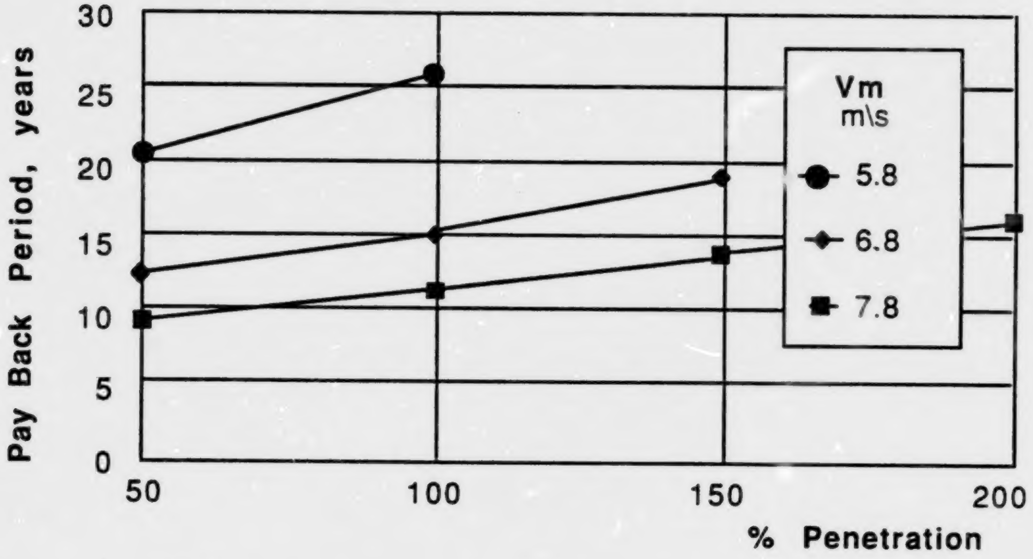


FIGURE 4 Pay Back Period

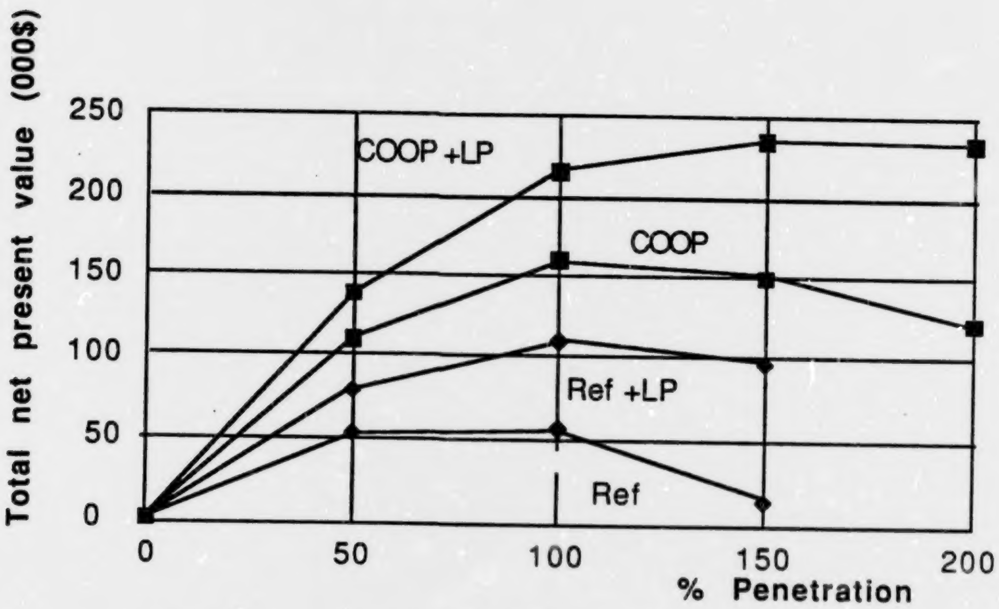


FIGURE 5 Total Net Present Value
Sensitivity analysis at Vm = 7.8 m/s

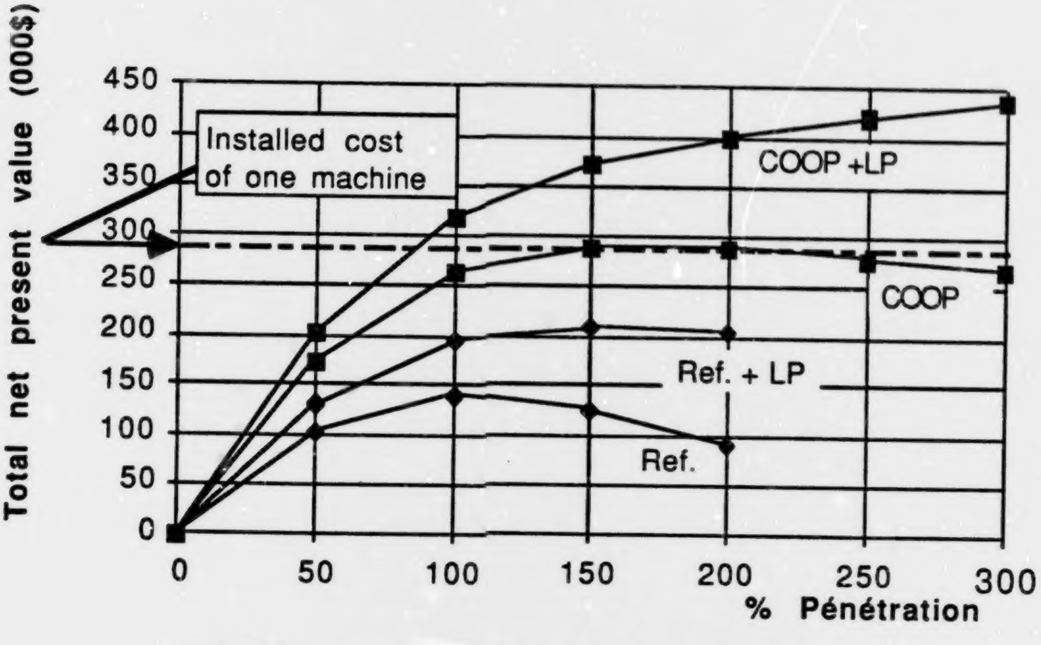
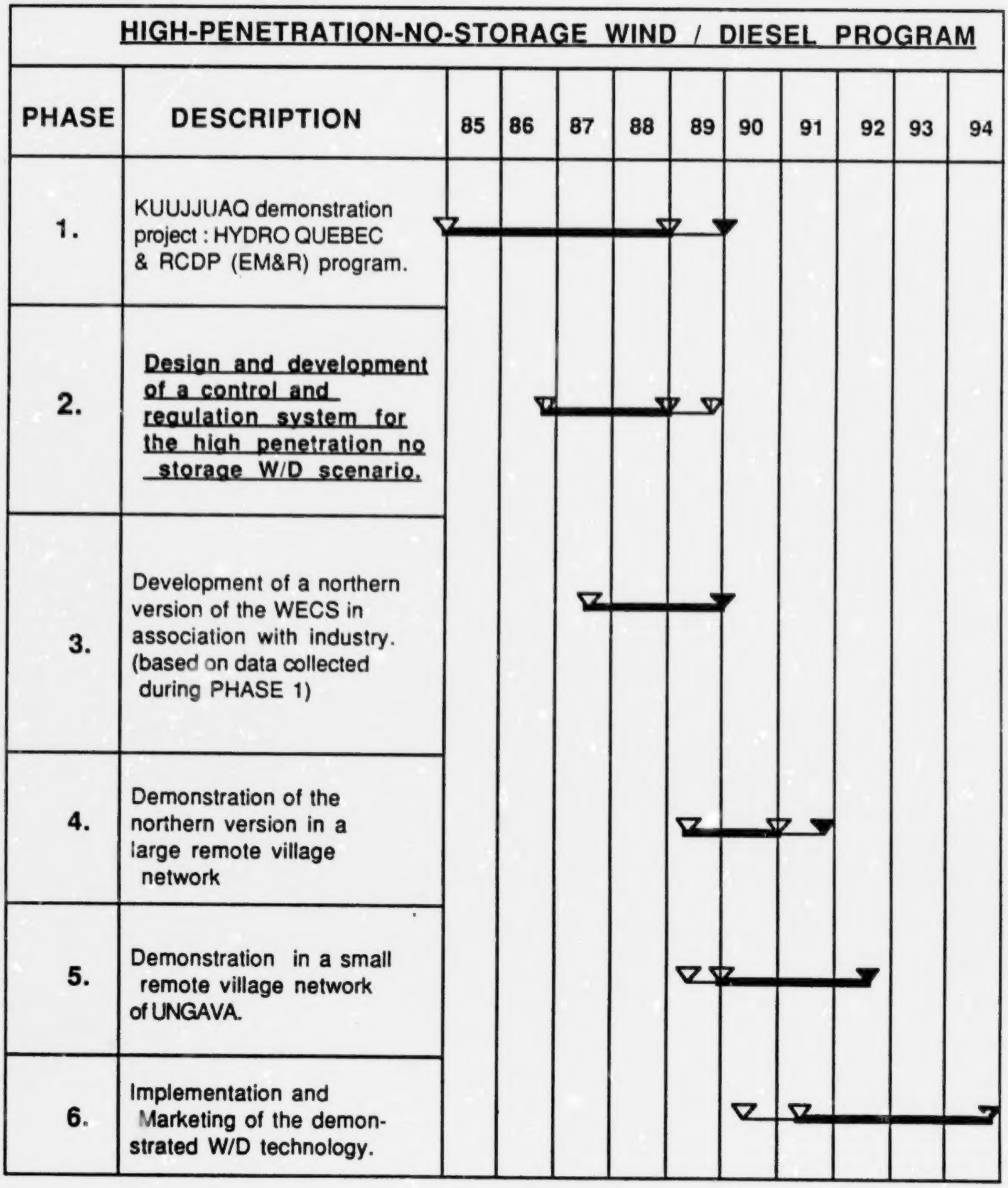


FIGURE 6 Total Net Present Value
Sensitivity analysis at Vm = 7.8 m/s

FIGURE 7

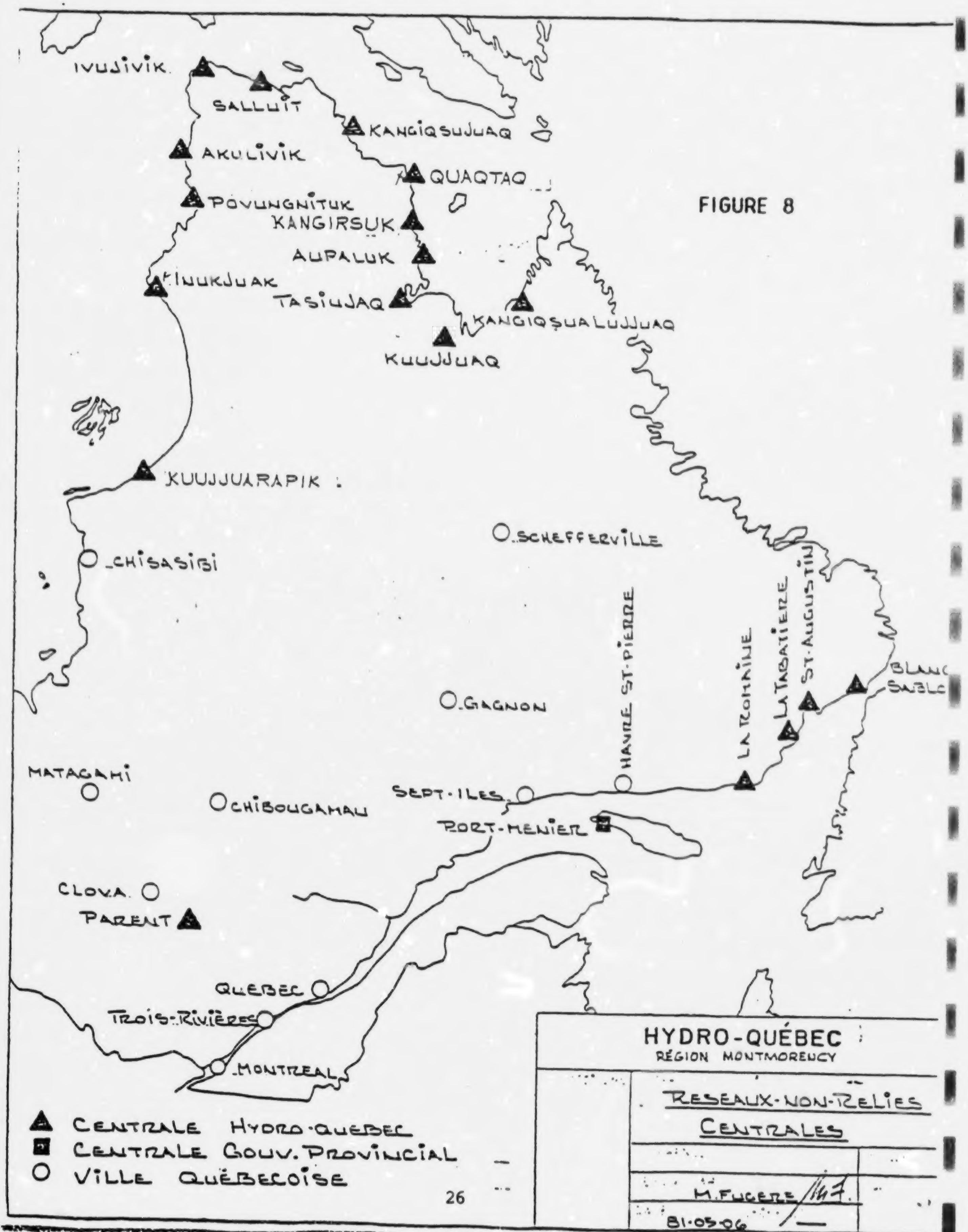
GLOBAL SCHEDULE OF WIND / DIESEL COUPLING PROGRAM



HIGH-PENETRATION-NO-STORAGE WIND / DIESEL PROGRAM

PHASE	DESCRIPTION
1.	KUUJJUAQ demonstration project : HYDRO QUEBEC & RCDP (EM&R) program.
2.	Design and development of a control and regulation system for the high penetration no storage W/D scenario.
3.	Development of a northern version of the WECS in association with industry. (based on data collected during PHASE 1)
4.	Demonstration of the northern version in a large remote village network
5.	Demonstration in a small remote village network of UNGAVA.
6.	Implementation and Marketing of the demonstrated W/D technology.

FIGURE 8


IVUJIVIK
SALLUIT
KANGIQSUJUAQ
AKULIVIK
QUAQTAQ
POVUNGNITUK
KANGIRSUK
AUPALUK
INUKJUAK
TASIUJAQ
KANGIQSUALUJJUAQ
KUUJJUAQ
KUUJJUARAPIK
SCHEFFERVILLE
CHISASIBI
HAVRE ST-PIERRE
LA ROMAINE
LA TABATIÈRE
ST-AUGUSTIN
BLANC
SABLO
GAGNON
MATAGAMI
CHIBOUGAMAU
SEPT-ILES
PORT-MENIER
CLOVA
PARENT
QUEBEC
TROIS-RIVIÈRES
MONTREAL
▲ CENTRALE HYDRO-QUEBEC
■ CENTRALE GOUV. PROVINCIAL
○ VILLE QUÉBECOISE

HYDRO-QUÉBEC
RÉGION MONTMORENCY

RESEAUX-NON-RELIES
CENTRALES

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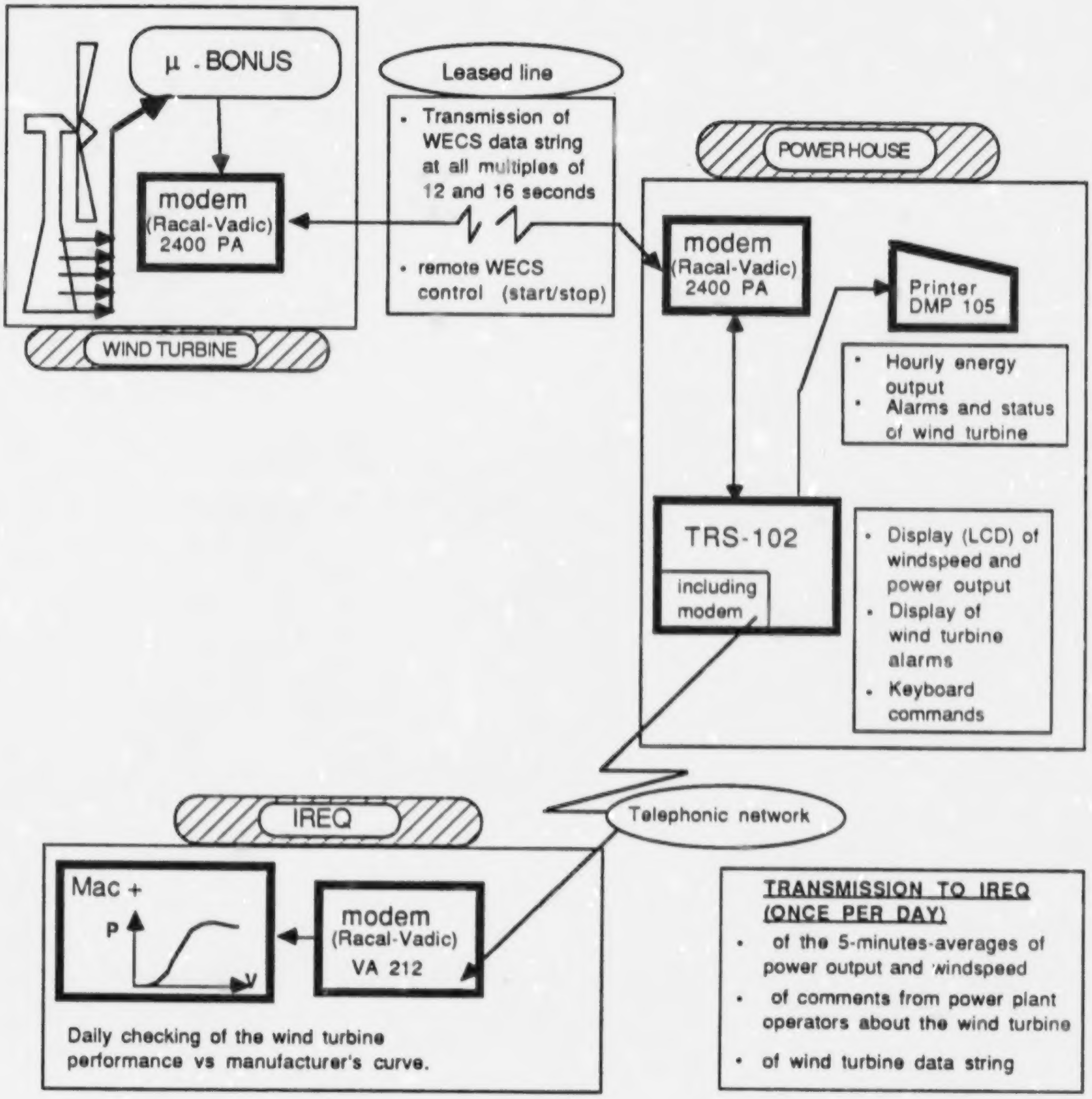

μ - BONUS
Leased line
• Transmission of WECS data string at all multiples of 12 and 16 seconds
• remote WECS control (start/stop)
modem (Racal-Vadic) 2400 PA
WIND TURBINE
POWER HOUSE
modem (Racal-Vadic) 2400 PA
Printer DMP 105
• Hourly energy output
• Alarms and status of wind turbine
TRS-102
including modem
• Display (LCD) of windspeed and power output
• Display of wind turbine alarms
• Keyboard commands
Telephonic network
IREQ
Mac +
P
V
modem (Racal-Vadic) VA 212
Daily checking of the wind turbine performance vs manufacturer's curve.
TRANSMISSION TO IREQ (ONCE PER DAY)
• of the 5-minutes-averages of power output and windspeed
• of comments from power plant operators about the wind turbine
• of wind turbine data string

FIGURE 9 INFORMATION TRANSMISSION FOR THE KUUJJUAQ'S WIND TURBINE

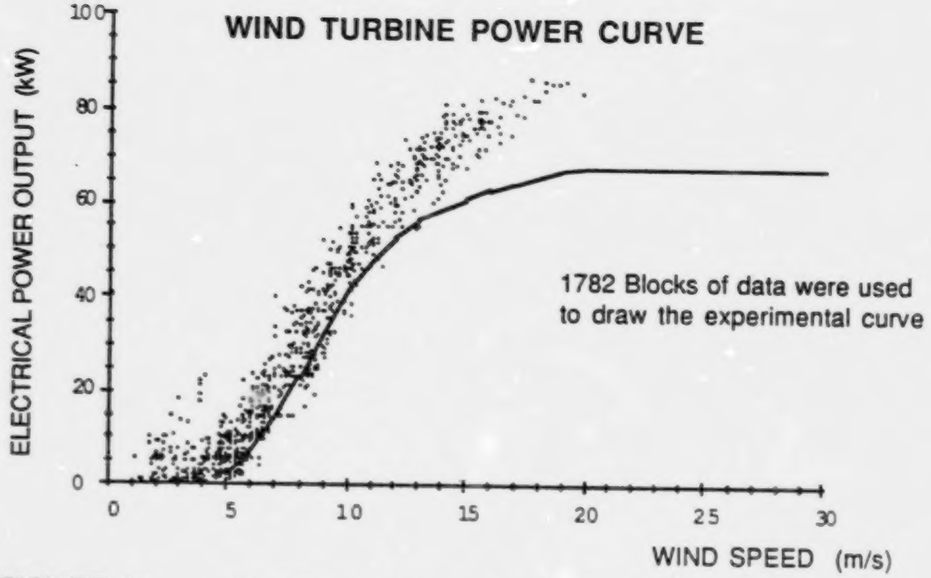


FIGURE 10 Experimental curve drawn from 5-minutes averages data points

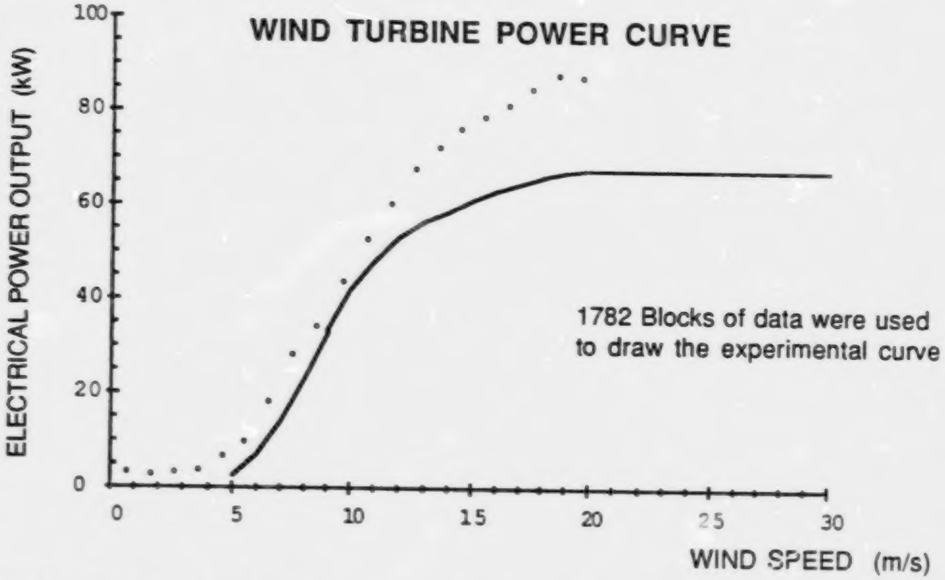
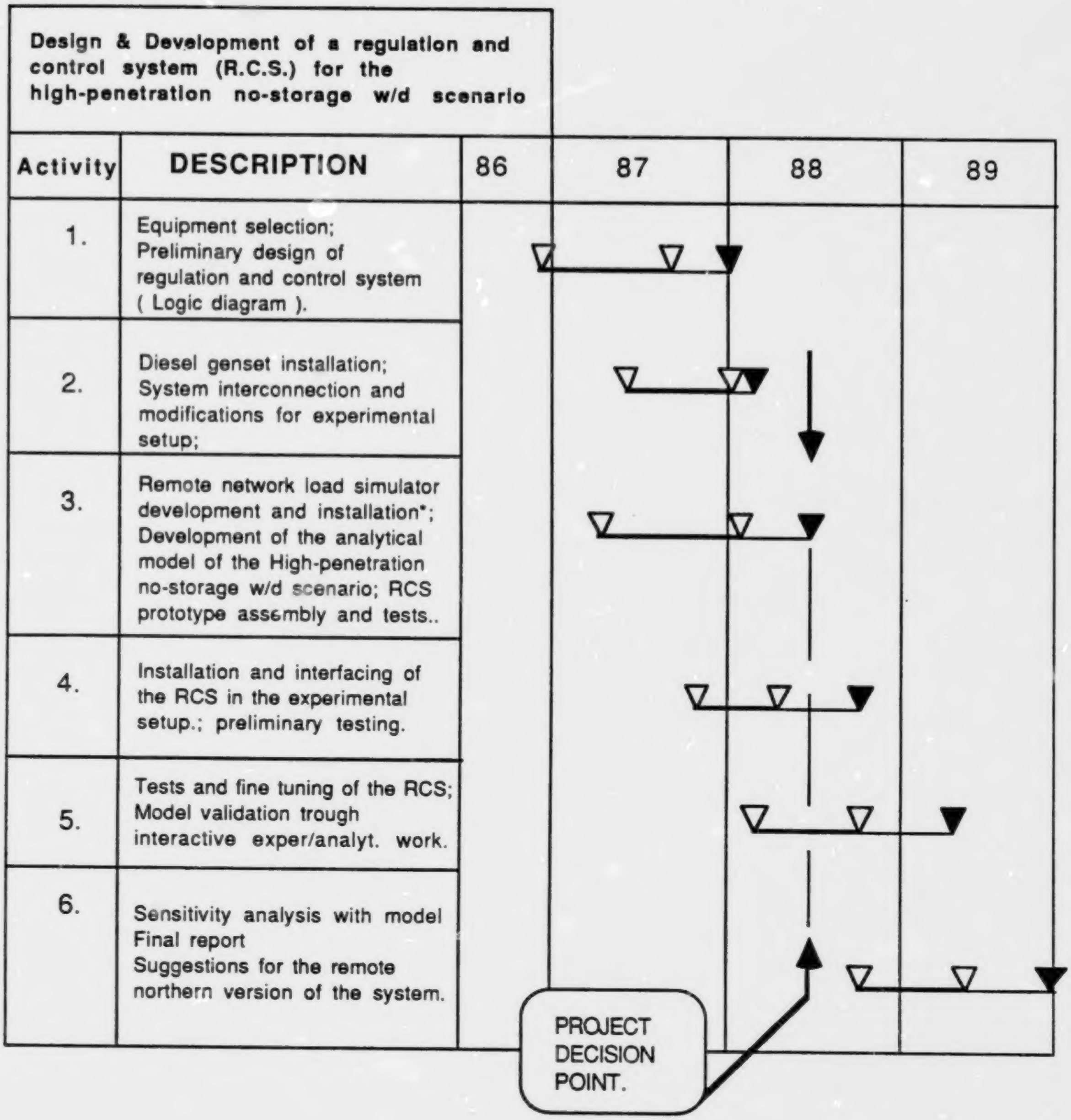


FIGURE 11 Experimental curve drawn from **binned** 5-minutes averages data points



Design & Development of a regulation and control system (R.C.S.) for the high-penetration no-storage w/d scenario

Activity	DESCRIPTION	86	87	88	89
1.	Equipment selection; Preliminary design of regulation and control system (Logic diagram).				
2.	Diesel genset installation; System interconnection and modifications for experimental setup;				
3.	Remote network load simulator development and installation*; Development of the analytical model of the High-penetration no-storage w/d scenario; RCS prototype assembly and tests..				
4.	Installation and interfacing of the RCS in the experimental setup.; preliminary testing.				
5.	Tests and fine tuning of the RCS; Model validation trough interactive exper/analyt. work.				
6.	Sensitivity analysis with model Final report Suggestions for the remote northern version of the system.				

FIGURE 12 WIND/DIESEL PROGRAM, PHASE 2

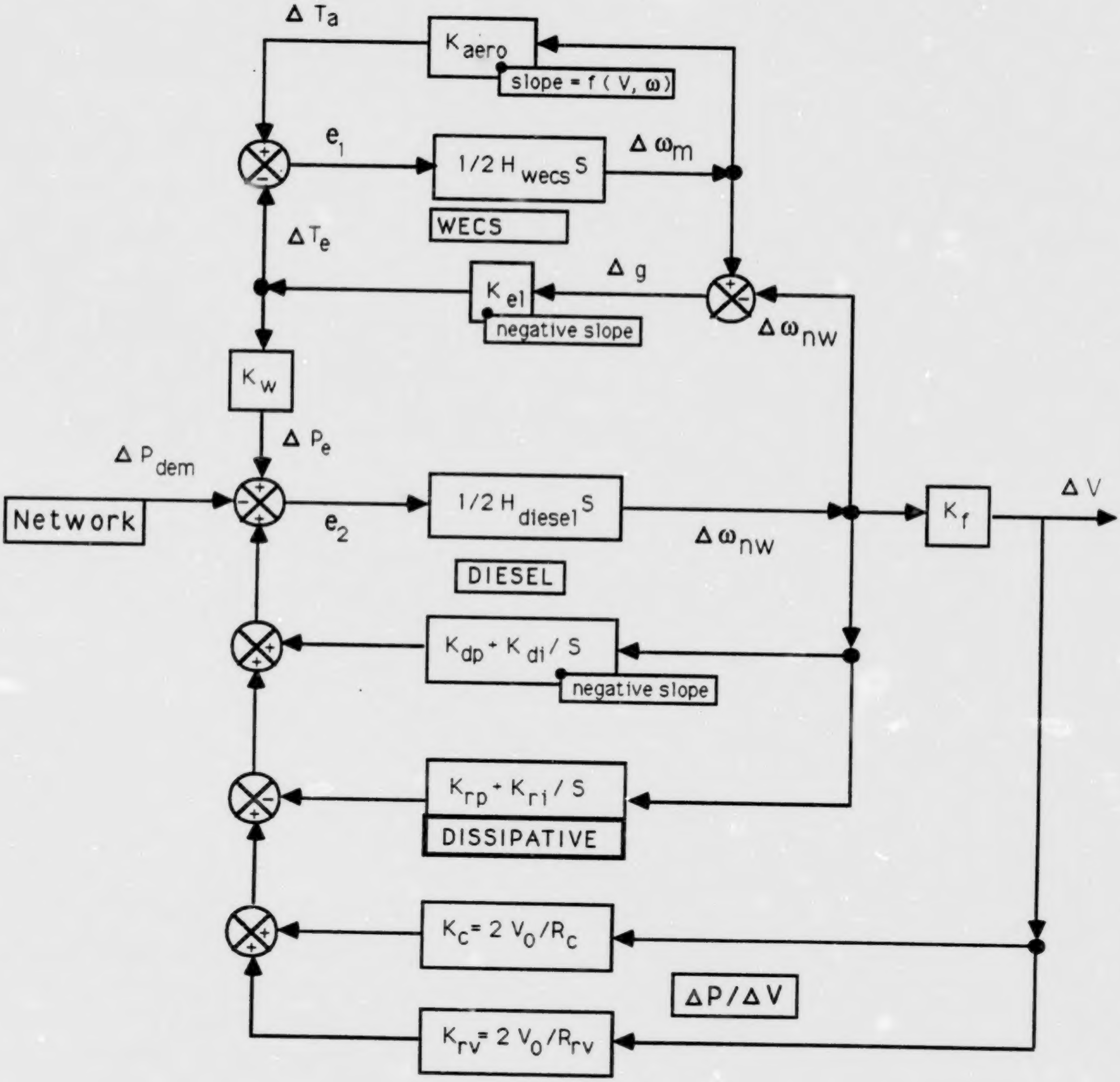

Δ Ta
K aero
slope = f (V, ω)
e1
1/2 H wecs S
Δ ωm
WECS
Δ Te
Δ g
K el
negative slope
Δ ωnw
K w
Δ Pe
Δ P dem
Network
1/2 H diesel S
e2
Δ ωnw
Kf
Δ V
DIESEL
Kdp + K di / S
negative slope
Krp + Kri / S
DISSIPATIVE
Kc = 2 V0 / Rc
ΔP/ΔV
Krv = 2 V0 / Rrv

FIGURE 13 No-storage Wind/Diesel scenario; Regulation Schematic

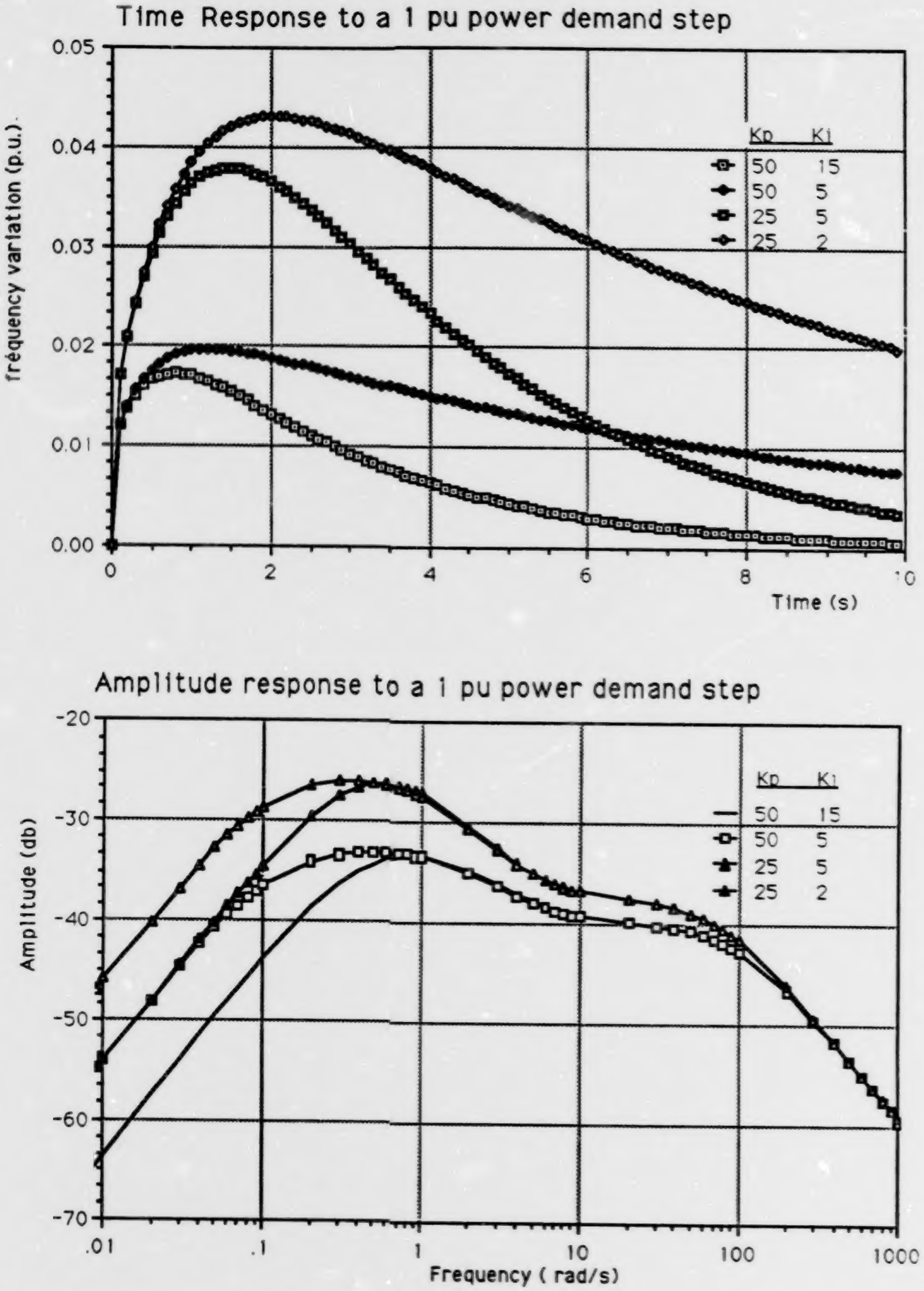


FIGURE 14 Time and frequency response to a 1 pu power demand step

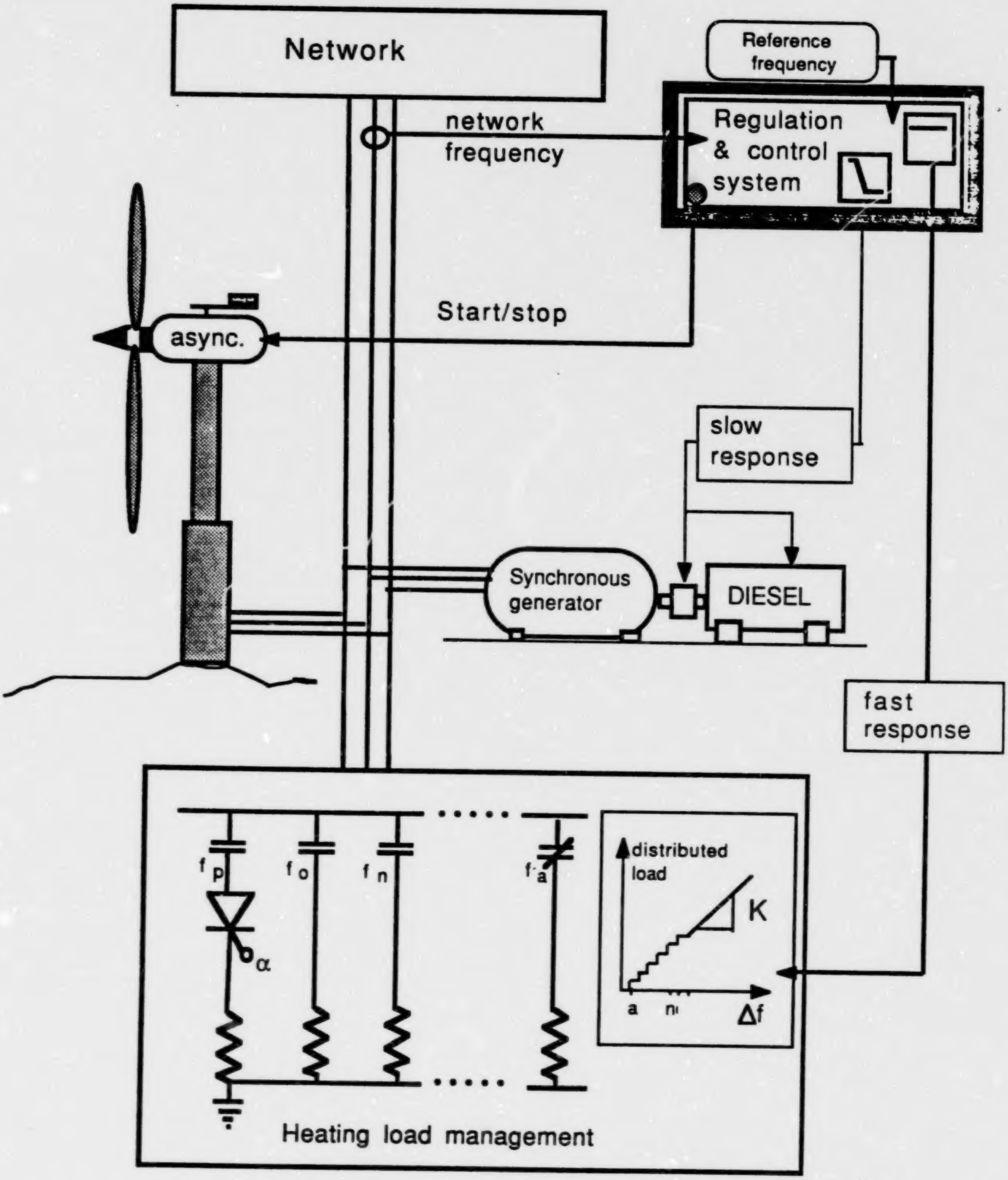

Network
network frequency
Reference frequency
Regulation & control system
Start/stop
async.
slow response
Synchronous generator
DIESEL
fast response
f p
f o
f n
f a
α
distributed load
K
a
n
Δf
Heating load management

FIGURE15 Schematic of the relations between the five major elements of the no-storage high -penetration W/D scenario.

APPENDIX 1

Transmission from BONUS WGT computer.

Here are informations incoming from BONUS, as we receice them from KUUJJUAQ:

```
 09/15/87
 0870 OK0240065139037 000178080038248100006493000134060003900
1300000729 0000410600002668000118800001221400000354 00000002
00000000001000000018000300000004012100020004000000000000000
000400000001200320066000000030002027300000000000000000000000
?<
```

After cutting-in the string in character groups, following information is available:

GENERAL RECORDS:

date:	sept 15. 1987
machine identification number:	0870
error code :	none (OK)
mean power on last 12 seconds:	24.0 kW
mean wind speed on last 16 seconds:	6.5 m/s
temperature of LARGE generator:	139 °C
temperature of SMALL generator:	37 °C
cumulative energy produced by small generator:	1780.8 kWh
cumulative energy produced by large generator:	38248.1 kWh
running hours of small generator:	649.3
running hours of large generator:	1340.6
running hours of WGT:	3901.3
running hours of yawmotor:	72.9
number of starts of small generator:	4106
number of starts of large generator:	2668
number of starts of yawmotor CW:	11880
number of starts of yawmotor CCW:	12214
number of slowing down of WGT during operation:	354

CANADA'S ARCTIC WIND FARM: CAMBRIDGE BAY, YEAR 1

Jason Edworthy
Michael Bourns
Nor'wester Energy Systems Limited

In early 1987, a Request for Proposal (RFP) was issued world-wide by Northern Canada Power Commission (NCPC) to supply a wind driven electrical generating system at Cambridge Bay, Northwest Territories, in northern Canada. Our firm responded, with Carter Wind Systems of Texas. In mid-May we were advised by letter that we had been awarded the work, and by mid-June a contract was in place.

Cambridge Bay Community

Cambridge Bay, known in Inuktitut as *Ikaluktutiak* , was begun in 1921 when the Hudson Bay Company opened a post. The site became well populated year-round when the DEW Line was set up in 1955. The hamlet lies on the southeast cost of Victoria Island, north of the mainland Arctic Coast.

The population numbers about 900, and occupations include work with the DEW Line, government activities, transportation industry and hunting or fishing.

The region is a recent glacial landscape, typically known as 'knob and kettle topography', including dry high spots and wet low spots. The surficial geology is made up primarily of gravels, boulder clays and frost fractured rock. There is very little vegetation in the region.

Regular air service is provided to Cambridge Bay by Canadian Airlines (formerly PWA) and Northwest Territorial Airways, using a gravel airstrip, usually with flights five times per week.

Marine transportation is usually via Northern Transportation Company Limited (NTCL) barges from Hay River, although Arctic Transportation Limited (ATL) operates barge services from the Mackenzie valley which may be chartered. NTCL required cargo for Cambridge Bay to be in Hay River by July 17 for this past summer.

There is one hotel in Cambridge Bay, with limited accommodation and meals, and bunkhouse accommodation.

The Cambridge Bay electrical grid consists of four diesel fueled generators (2 x 720 kW, 1 x 560 kW, 1 x 375 kW, total capacity 2.375 kW). The peak demand is about 1.1 MW, minimum demand is 320 kW, and total annual load is about 5,000 MWhr. Retail electrical prices range about 35¢ to 45¢/kWhr.

Cambridge Bay Wind Regime

The wind energy resources available at Cambridge Bay are adequate for wind energy use, although they do not compare with such popular wind power locations as southern California or the coasts of Scandinavia. There are sufficient resources for wind energy to be considered an appropriate alternative to expensive diesel fueled energy.

Like many high latitude locations, mean monthly winds peak twice per year at Cambridge Bay, in the summer/early winter (August to October) and in mid-winter (January and February). The autumn peak is the highest, averaging 23.2 km/h over the quarter year. The lowest wind speeds occur in late winter and spring (March through July), averaging 21.04 km/hr for the period, indicating that there is little real seasonal variation.

The mean annual wind speed for Cambridge Bay is 21.8 km/hr (13.5 mph, 6.05 m/s). Winds are primarily from the north, with high frequency from the northwest and west directions. Maximum winds observed are to 122 km/hr (75.6 mph, 33 m/s), which are well below design maximums for most windplant models.

Carter Model 25 Windplants

Our proposal was based on the use of four Carter Model 25 units, each rated at 25 kW power, to provide a 100 kW wind farm project.

The specifications for the Model 25 units installed at Cambridge Bay are given in Table 1.

Few modifications were proposed in the units for use in the Arctic. Low temperature transmission lubricants were used, as were arctic grade greases for bearings. A small electric heater was installed on the transmission, similar to an automobile block heater, to assist in cold weather protection.

Because Cambridge Bay is located in an area of continuous permafrost, special considerations for the foundations were required. In consultation with a geotechnical engineering firm in Calgary, and with Carter, we developed a drilled-pile adfreeze foundation system suitable for the Carter 24 m (80 ft) tipping tower. The foundation for each windplant consists of six 6 m long steel pipe piles placed in drilled holes and frozen in to place. Such foundations are commonly used in compression in the Arctic for buildings.

Table 1. Carter Model 25 Specifications for Cambridge Bay

Item		Model 25
GENERATOR	type	Induction, AC
	cut-in windspeed	13.7 km/h. 8.7 mph
	power rating @ windspeed	25 kW @ 41.9 km/hr, 26 mph
	peak power @ windspeed	30 kW @ 64.5 km/hr, 40 mph
	cut-out windspeed	none
	maximum tested windspeed	200 km/hr, 125 mph
	power factor without capacitors	.77 @ 25 kW
	voltage	480
	phase	3 Ø, wye or delta
	efficiency @ rated power	92%
ROTOR	number of blades	2
	blade material	fibreglass composite
	blade pitch	fixed
	blade design	non-linear twist, taper
	configuration	horizontal axis, downwind
	diameter	9.9 m, 32.5 ft
	power limiting	aerodynamic stall
	hub material	steel
	total weight	134 kg,295 lbs
TRANSMISSION		
	type	double red, round helical
	ratio	15.3:1
	efficiency @ rated power	96%
	cold weather protection	electric heating element
ORIENTATION	type	free yaw (tail cone)
BRAKING	type	self-adjusting, spring-loaded
	activation	automatic with overspeed or loss of voltage
CONTROLS	type	Custom CPU, SSC-4
	software	built in to onboard ROM
	displays/controls	LED digital display, front panel keypad
	safety features	voltage, frequency matching to grid
	power sourcing	grid/WECS with line loss failsafe shutdown
NACELLE	material	fibreglass composite
	size (LxWxH)	1.6mx0.76mx0.91m,5.25'x2.5'x3'
TOWER	type	tilt-up
	number of guys	4
	height	24 m, 80 ft recommended
	foundations	concrete/rebar (or Arctic adfreeze/thermopiles optional)
	weight	1160 kg, 2551 lbs
GENERAL	design Life	20 years
	service schedule	change oil yearly, lube every 6 months
	Warranty period	2 years (optional 5 year)
	total weight of system, including tower	1770 kg, 3891 lbs

Description of the Installation

Most of the equipment for the project was delivered to Hay River, NWT, by July 17, by truck. Hay River is the terminus for the barge system in the western Arctic, and from there the equipment left around the end of August to travel down the Mackenzie River to Tuktoyaktuk. The barges for Cambridge Bay and surrounding areas then travel east in the Arctic Ocean, usually close to the mainland coast to the various communities. Schedules depend heavily on whether or not sea ice has cleared from the region. The barged equipment arrived in Cambridge Bay about August 20.

The foundations were installed in early August, which provided over four weeks for complete freezing-in before the windplants were installed on them.

The balance of the equipment and the installation crew travelled to Cambridge Bay the first week of September. All 2000 kg of gear were air freighted. The personnel arriving at Cambridge Bay included one Carter technical representative, to supervise and assist with installation and commissioning.

The installation took approximately two weeks, and included final welding work on the piles, moving of equipment to the site, assembly of the towers and guying system, installation of the yaw assembly, generator pod, blades and tail cone, and erection. The electrical work was conducted under the supervision of a local electrician. Additional crew help was secured locally from contractors and NCPC, and included a number of native townspeople.

On September 15 the wind farm transformer was connected to the utility grid and energized. Each windplant was individually tested, then started as part of the commissioning process. By the evening of that day, all four windplants were placed on-line for initial run-in testing and operation.

Current Status

As of this date in late September, the commissioning process is still under way and is expected to be completed in late October or early November. Electrical problems encountered in the stators of two machines early in the operational testing have warranted examination of those components at the manufacturer's facilities, for diagnosis and correction. These components are being shipped south during the next week. All units will remain shut down until this process has been completed and the manufacturer returns the parts in operational condition.

Problems Encountered

Most of the problems encountered were of the type expected, and have included poor weather, difficult freight delivery schedules, high costs (air travel, freight, accommodation, vehicle and heavy equipment rental costs). The site for the installation was changed early in the work from a location about 1 km from the townsite to another about 4 km away, and this has resulted in additional time and rental charges, due to the difficult nature of road travel there. There are some unique aspects to working with townspeople in northern communities, sometimes related to language difficulties but at other times related to opportunites to hunt or fish, when the weather and travel conditions present them.

There were few technical problems associated with the Carter equipment during assembly and installation. Initial performance of the machines was good until the electrical problems developed. The reasons for this problem will be assessed when the equipment components are examined in the factory, and these will be corrected before commissioning continues next month.

Conclusion

The project is scheduled to be fully operational and commissioned by January 1988. The project was brought North and installed under a very tight time schedule of strict milestones, such as the barge deadline. The project has proceeded at a rate very close to that anticipated in the schedule. We anticipate that performance during the first year will be reported at this conference next year.

Acknowledgements

A large number of people have contributed their efforts to this project. NCPC's plant superintendent at Cambridge Bay, George Dion, and his crew, have been very supportive and enthusiastic, and have contributed generously in assisting us in the work. Other individuals involved directly in the project include John Allan of NCPC in Edmonton, Leon Urban of NCPC in Yellowknife and Malcolm Lodge of Resource Ventures Inc. Energy, Mines and Resources personnel with whom we have had dealings in this project include Monique Carpentier and Jim Cummings; the RCDP program is managed by Elliot Rodger. We wish also to acknowledge the contributions of our subcontractors, Fred Ross and Associates of Cambridge Bay, Canadrill of Iqaluit, and Thurber Consultants of Calgary.

PROJECT EOLE

S. Quraeshi and B. Richards
Shawinigan Lavalin Inc.
1100, Dorchester Boulevard West, Montreal, Quebec, Canada H3B 4P3

INTRODUCTION

A 4 MW vertical-axis, Darrieus wind turbine generator, designated EOLE, has been constructed near Cap-Chat, Quebec, Canada by Shawinigan-Lavalin Inc. The project was jointly funded by Hydro-Quebec and National Research Council of Canada.

The configuration of EOLE and the design details are shown in Figures 1 to 10. Its principal characteristics are listed below:

EOLE PARAMETERS

Turbine shaft power rating = 4 MW
Rated rotational speed = 14.25 rpm
Swept area = 4000 m^2
Number of blades = 2 at 180 degrees
Height/diameter ratio = 1.5 (96 m/64 m)
Solidity = 0.15
Equatorial height/rotor height = 1.25
Blade airfoil section = NACA 0018 (2.4 m corde)
Rotor shape = Nominal troposkein (straight-circle-straight)

TURBINE

Central column = 12 mm rolled and welded plate steel in 6 sections of 5 m diameter.
Column damper = 18 tonne suspended and tuned mass.
Blades = 5.7 m long straight sections with straight or angled bolted joints as required.
Nose and tail are fibreglass bolted to the 6 mm steel structural box section.
Blade joints and outer third of horizontal struts are provided with fibreglass fairings.
Spoilers = 9 pairs per blade hydraulicly actuated.

GUY CABLE SUPPORT SYSTEM

The wind turbine is supported by a guy cable system having the following parameters:

Number of guy cables = 6
Type of cable = Bridge strand Class A
Size of cable = 76 mm diameter
Initial tension = 800 kN per cable
Nominal cable inclination = 35 degrees
Natural frequency = First mode is increased above the turbine 2-P by means of mid-span cable support masts.
Cable end-fittings = Suspension bridge type with epoxy-resin socketing.

DRIVE TRAIN

The base of the wind turbine rotor column is coupled to the generator by a drive train consisting of the following components.

Pivot = Flexible link coupling and elastomer support pad.
Wind turbine inclination allowable 3° from vertical.
Turbine bearings = Spherical roller thrust and guide
Bottom oil lubricated
Top grease lubricated
Mechanical brake = Two 5 m diameter, 50 mm thick steel discs.
Three spring-applied, air-released calipers per disc.
5400 kNm total torque
Flexible coupling = Resilient type with 16 pre-loaded elastomeric cylindrical elements.

GENERATOR AND ELECTRICAL SYSTEM

Generator = Directly-coupled, 3.6 MW
0.9 power factor 3 ph 19.24 Hz
162 poles, 3160 volts, synchronous
Vertical shaft, 2 bearing force-cooled.
Excitation = Static exciter with constant flux control.
Emergency braking excitation from battery.

GENERATOR AND ELECTRICAL SYSTEM (CONT'D)

Static frequency converter (SFC) = 0 to 20 Hz at generator to 60 Hz grid. Back-to-back, 6 pulse Graetz bridges. 4 thyristors in series per arm. 3.6 MW cont. 6 MW for 20s for regenerative braking.

Main transformer = Delta-star, 69/4.16 kV, 6.5 MVA ON cooled

Auxiliary transformer = 4160/600 volts, 750 kVA dry-type. Load includes generator excitation.

Harmonic filters = 5th and 7th harmonic filters on the grid side of the SFC.

Emergency resistance braking = 3 phase, star-connected resistor bank rated for 6 MW for 30s for generator loading.

CONTROL SYSTEM

Static frequency converter = Micro-processor to program the low speed starting sequence, the d.c. current regulator, the speed regulator and 2-pole Butterworth speed filter.

Overall machine control = Redundant programmable controllers with bumpless transfer. Controls all operational sequences and provides the rotational speed reference. An independent microcomputer is provided for off-line programming and debugging the system.

OPERATION AND PROTECTION

Operating modes = The rotational speed reference is controlled as a function of wind speed according to the operating mode as shown in Figure 1.

Protection = In the event of any fault in the system, the stopping sequence is selected in accordance with the location of the fault.

OPERATION AND PROTECTION (CONT'D)

Fault categories: CAT 1 = regenerative braking; mechanical brake below 25% speed.

CAT 2E = emergency resistance braking; aerobrakes + (1 disc) mechanical brake below 25% speed. Normal excitation.

CAT 2E = emergency resistance braking; aerobrakes + mechanical brake (1 disc) below 25% speed. Emergency battery excitation.

CAT 3 = Aerobrakes + mechanical brakes (2 discs).

INSTRUMENTATION

= 120 data channels scanned at rates up to 5000 samples per second.

= Fiber optic with (optical slipring) links the data from the rotating system to the control rooms.

= Data essential to operation are routed to the PC and vice-versa over an RS232C serial link.

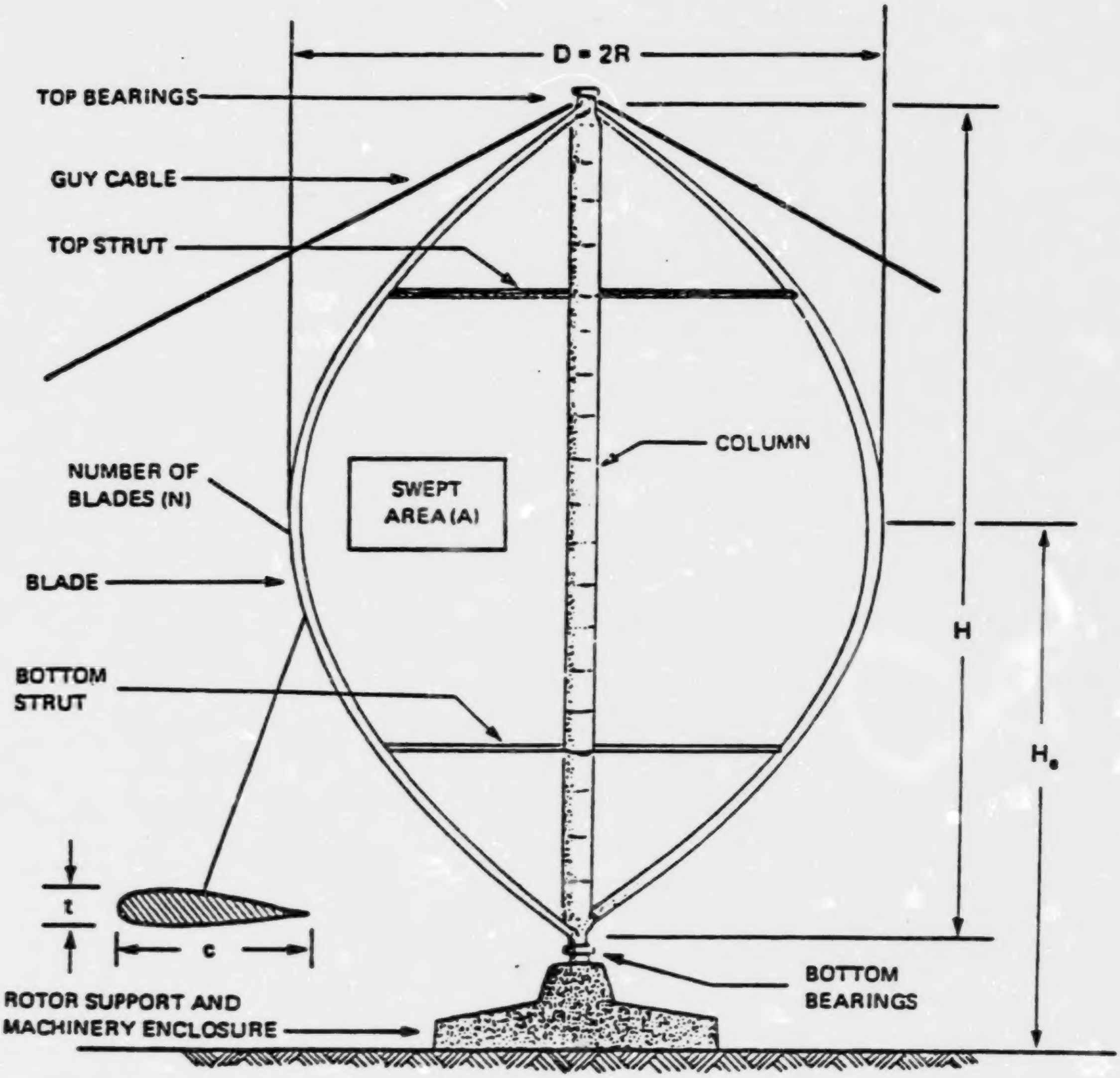
= A microcomputer with printer is provided for data acquisition.

= A minicomputer with plotter and printer is provided for data analysis.

= A two screen colour graphic system with hard copy printer is provided for alarm display, access to any part of the system for information and selection of mode of operation.

CONCLUSION

EOLE has been commissioned and is currently being evaluated against the design. Results to date are encouraging.


D = 2R
TOP BEARINGS
GUY CABLE
TOP STRUT
COLUMN
NUMBER OF BLADES (N)
SWEPT AREA (A)
BLADE
H
H_e
BOTTOM STRUT
t
c
BOTTOM BEARINGS
ROTOR SUPPORT AND MACHINERY ENCLOSURE

$A = 4000\ m^2$
$H = 96\ m$
$D = 64\ m$
$N = 2$
$t = 0.43\ m$
$c = 2.4\ m$

Fig. 1 – Project EOLE Parameters Specified in the Project Definition.

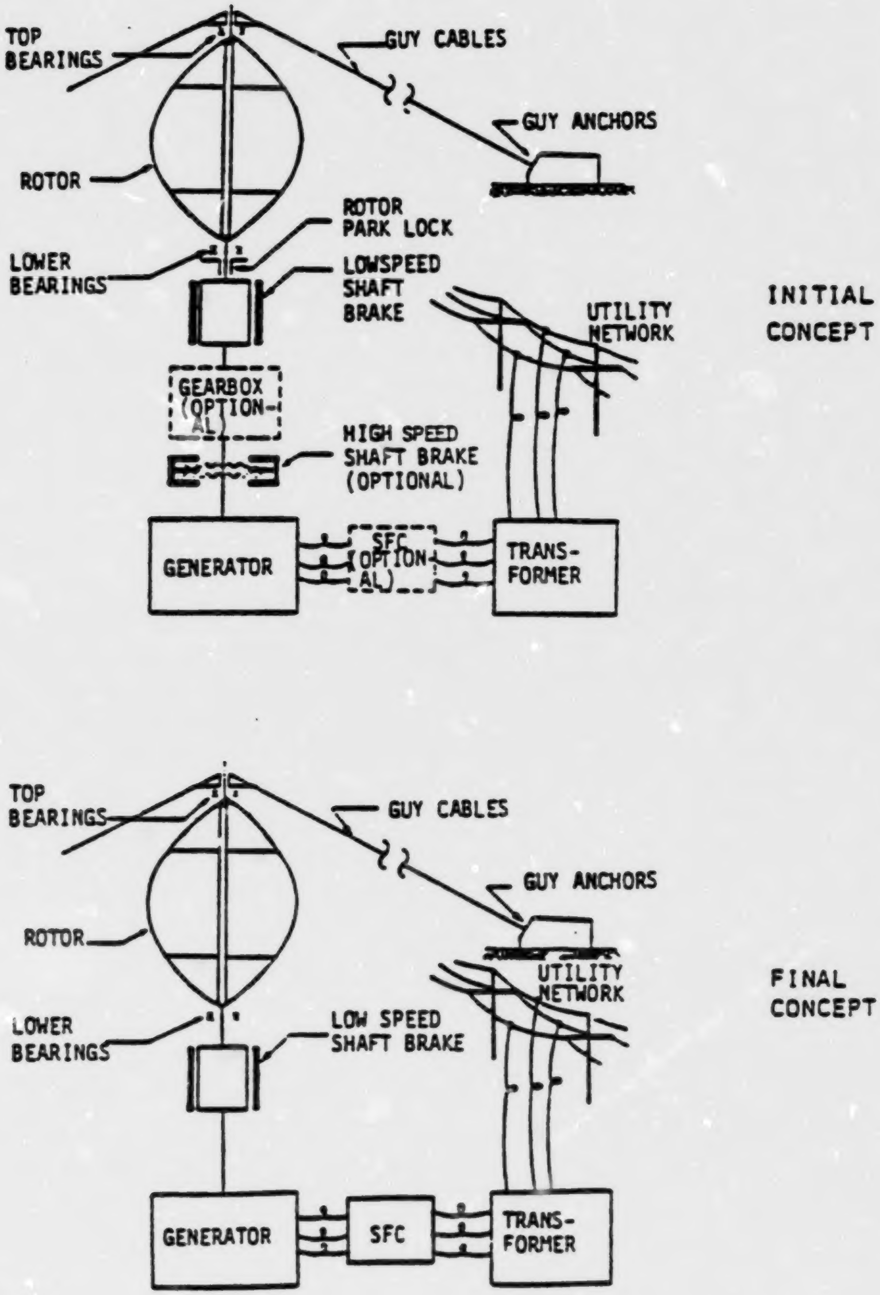

TOP BEARINGS
GUY CABLES
GUY ANCHORS
ROTOR
ROTOR PARK LOCK
LOWER BEARINGS
LOWSPEED SHAFT BRAKE
UTILITY NETWORK
INITIAL CONCEPT
GEARBOX (OPTIONAL)
HIGH SPEED SHAFT BRAKE (OPTIONAL)
GENERATOR
SFC (OPTIONAL)
TRANSFORMER
TOP BEARINGS
GUY CABLES
GUY ANCHORS
ROTOR
UTILITY NETWORK
FINAL CONCEPT
LOWER BEARINGS
LOW SPEED SHAFT BRAKE
GENERATOR
SFC
TRANSFORMER

Fig. 2 - Project EOLE Basic Concepts.

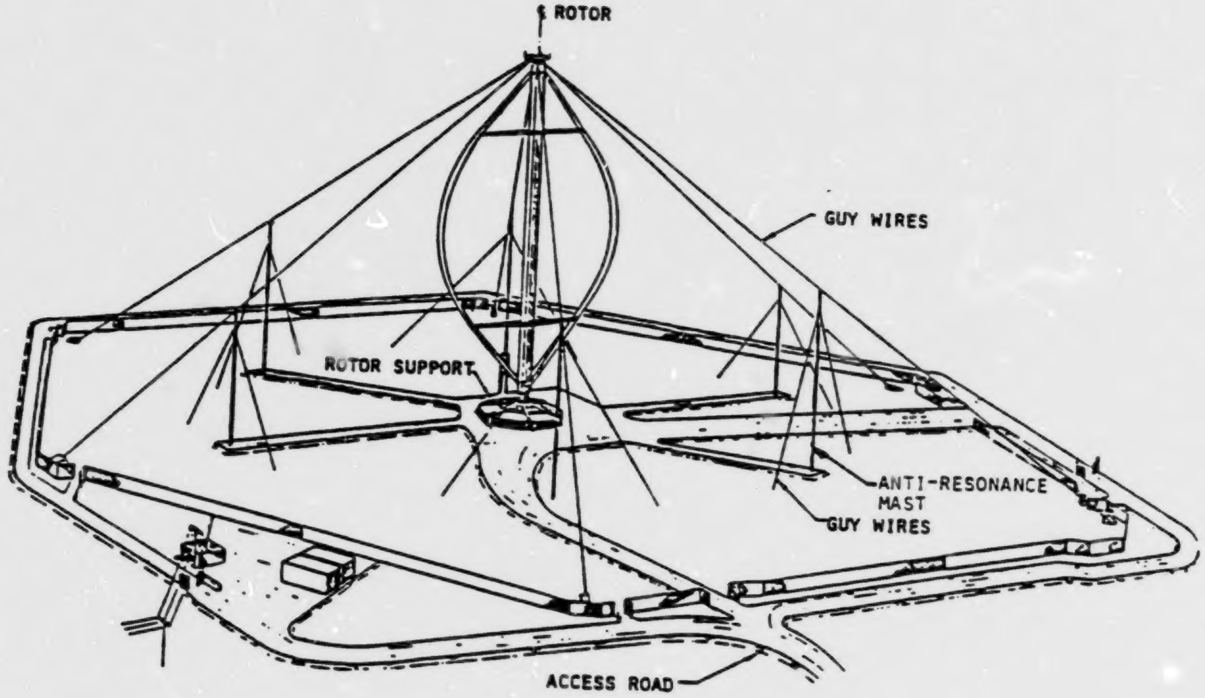

℄ ROTOR
GUY WIRES
ROTOR SUPPORT
ANTI-RESONANCE MAST
GUY WIRES
ACCESS ROAD

Fig. 3 - Project EOLE Design Configuration.

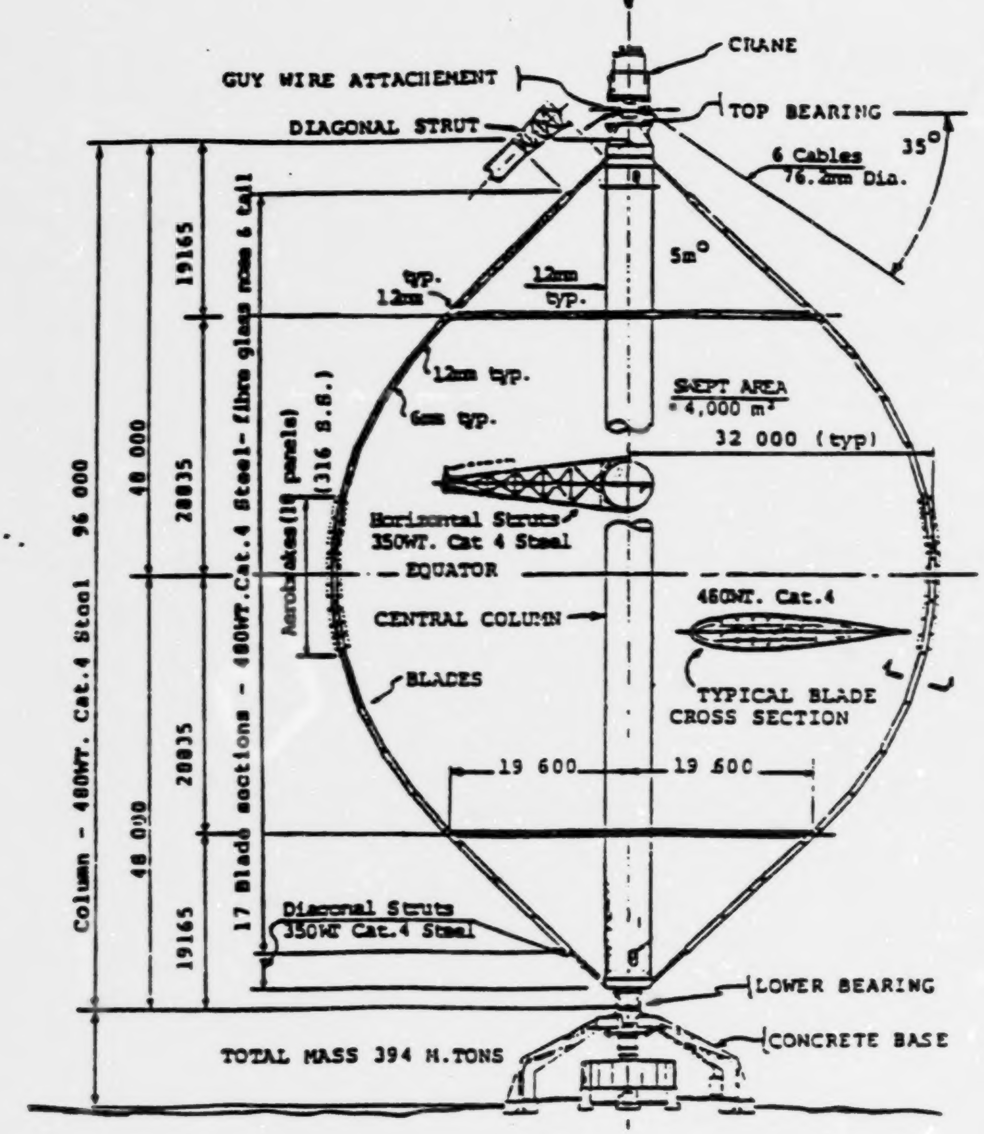
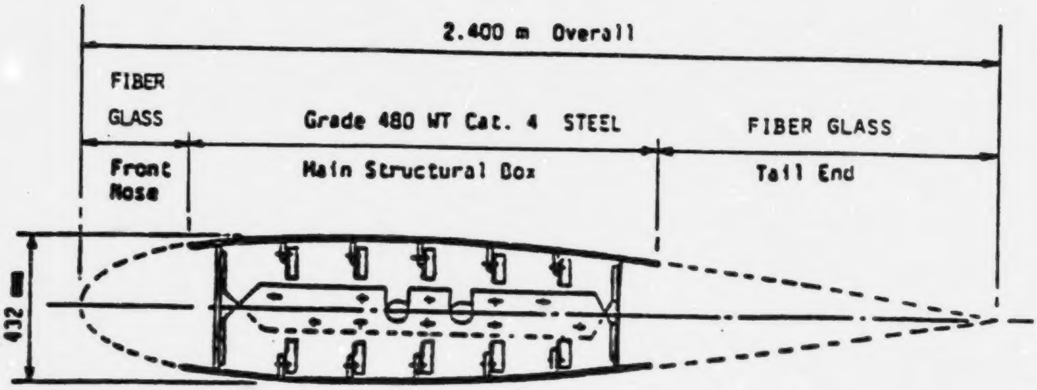
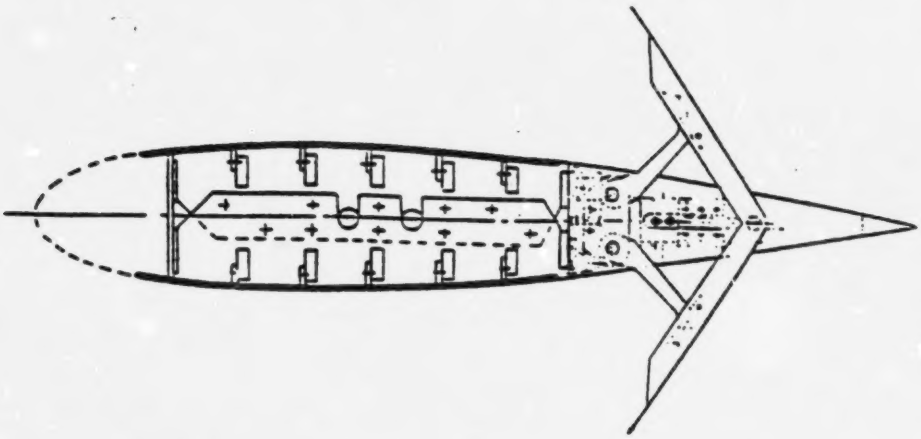

CRANE
GUY WIRE ATTACHEMENT
DIAGONAL STRUT
TOP BEARING
35°
6 Cables
76.2mm Dia.
5m°
typ.
12mm
12mm
typ.
12mm typ.
6mm typ.
SWEPT AREA
= 4,000 m²
32 000 (typ)
Horizontal Struts
350WT. Cat 4 Steel
EQUATOR
460WT. Cat.4
CENTRAL COLUMN
BLADES
TYPICAL BLADE
CROSS SECTION
19 600
19 600
Diagonal Struts
350WT Cat.4 Steel
LOWER BEARING
CONCRETE BASE
TOTAL MASS 394 M.TONS
Column - 480WT. Cat.4 Steel 96 000
48 000
48 000
19165
28835
28835
19165
17 Blade sections - 480WT.Cat.4 Steel- fibre glass nose & tail
Aerobrakes(18 panels)
(316 S.S.)

Fig. 4 - Rotor Structural Details.


2.400 m Overall
FIBER GLASS
Grade 480 WT Cat. 4 STEEL
FIBER GLASS
Front Nose
Main Structural Box
Tail End
432 mm

a) - Normal Blade Section.



b) - Blade Section Including Aerodynamic Brake.

Fig. 5 - Rotor Blade Sections.

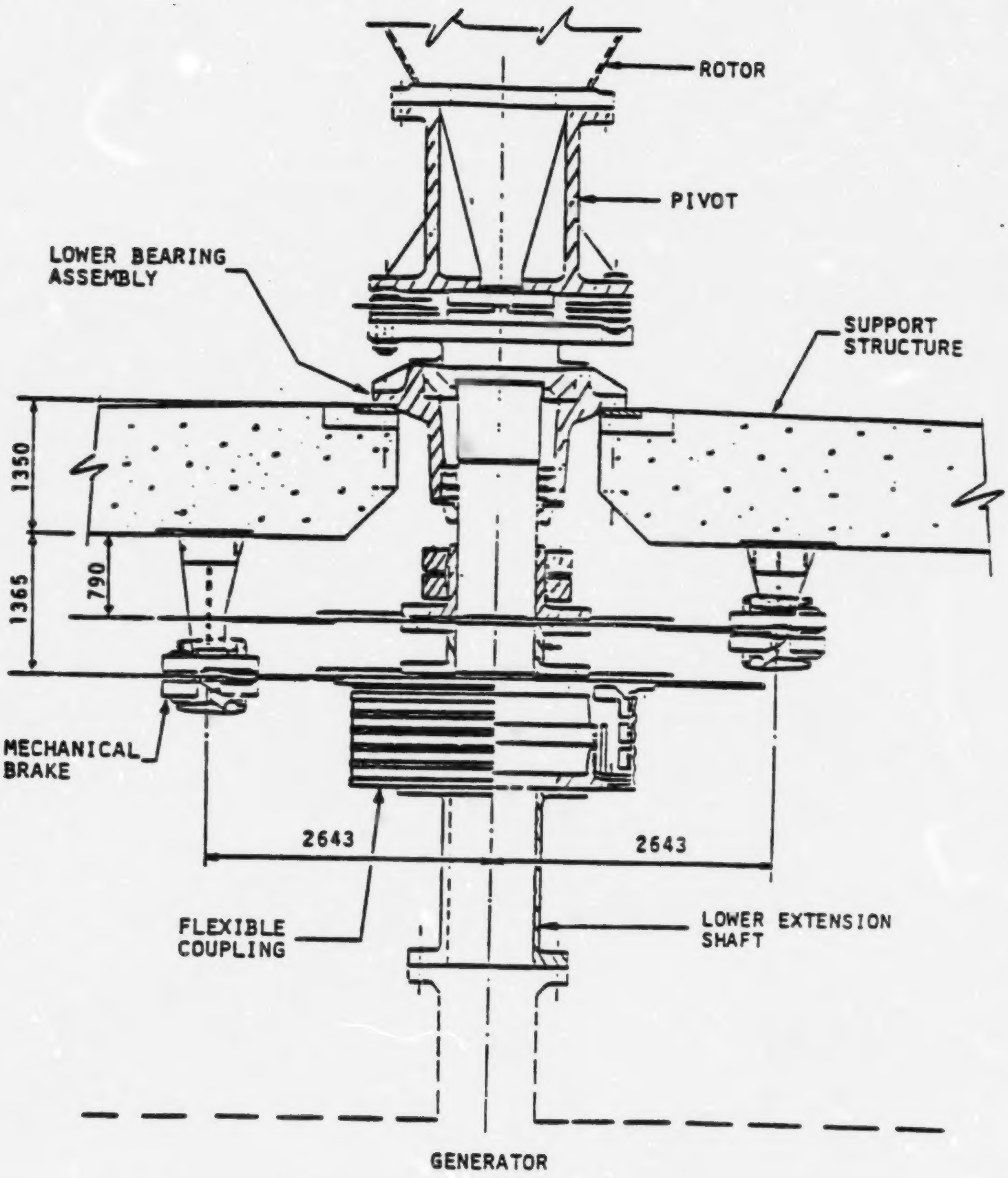

ROTOR
PIVOT
LOWER BEARING ASSEMBLY
SUPPORT STRUCTURE
1350
1365
790
MECHANICAL BRAKE
2643
2643
FLEXIBLE COUPLING
LOWER EXTENSION SHAFT
GENERATOR

Fig. 6 - Mechanical Drive Train Arrangement.

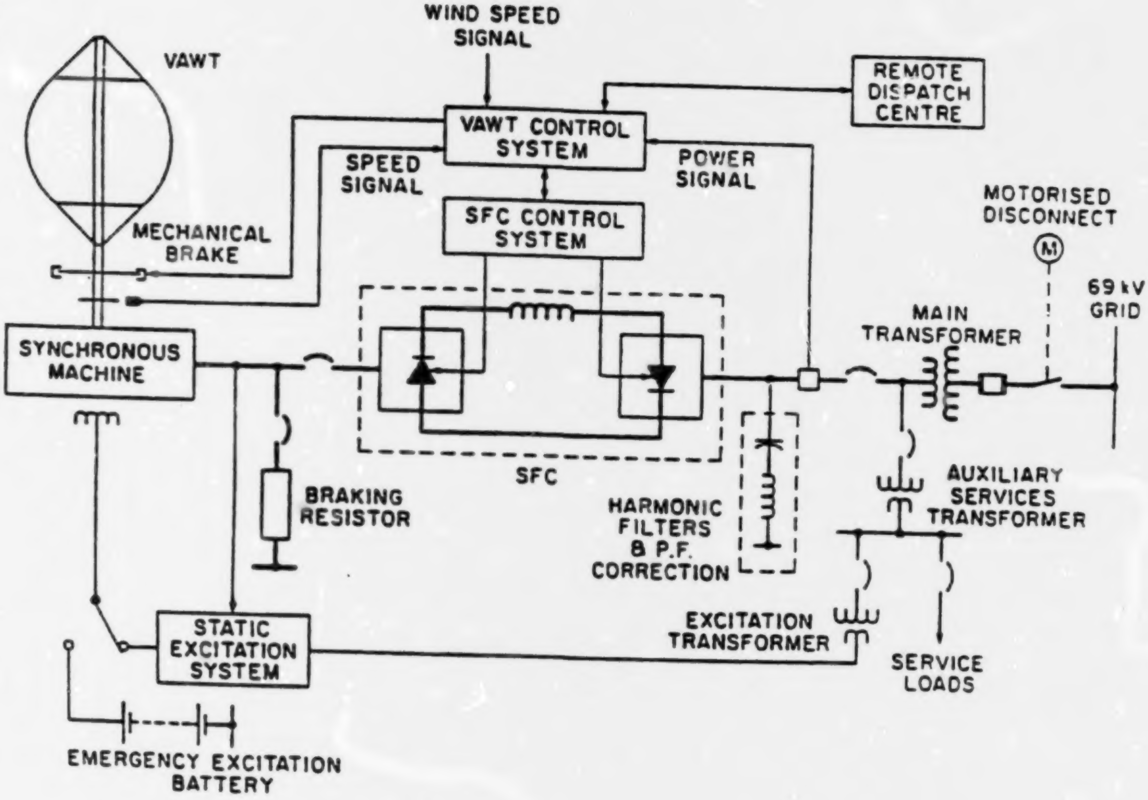
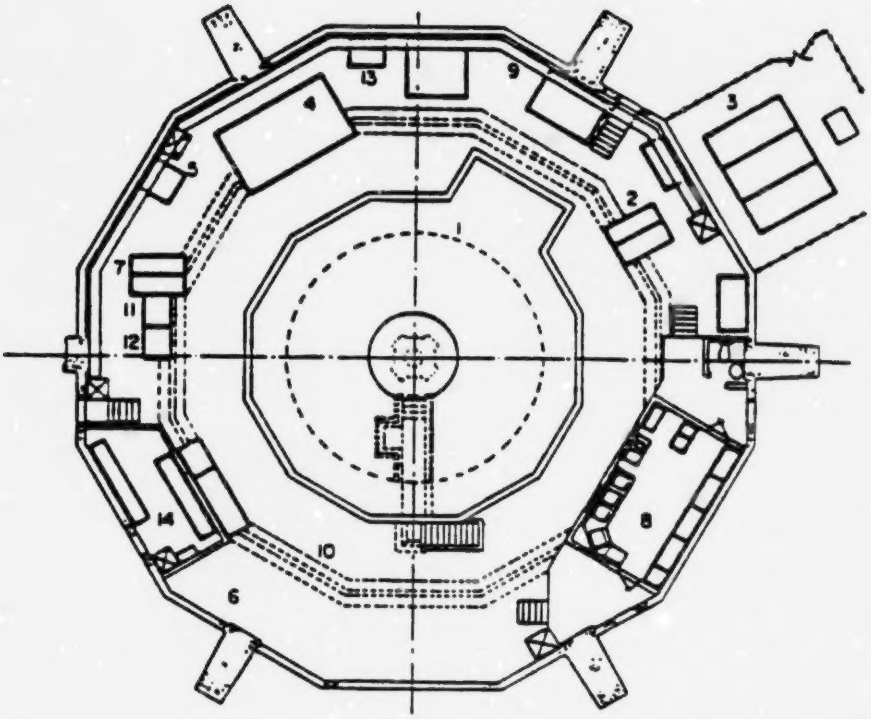

WIND SPEED SIGNAL
VAWT
REMOTE DISPATCH CENTRE
VAWT CONTROL SYSTEM
SPEED SIGNAL
POWER SIGNAL
MOTORISED DISCONNECT
M
SFC CONTROL SYSTEM
MECHANICAL BRAKE
69 kV GRID
MAIN TRANSFORMER
SYNCHRONOUS MACHINE
SFC
AUXILIARY SERVICES TRANSFORMER
BRAKING RESISTOR
HARMONIC FILTERS & P.F. CORRECTION
EXCITATION TRANSFORMER
STATIC EXCITATION SYSTEM
SERVICE LOADS
EMERGENCY EXCITATION BATTERY

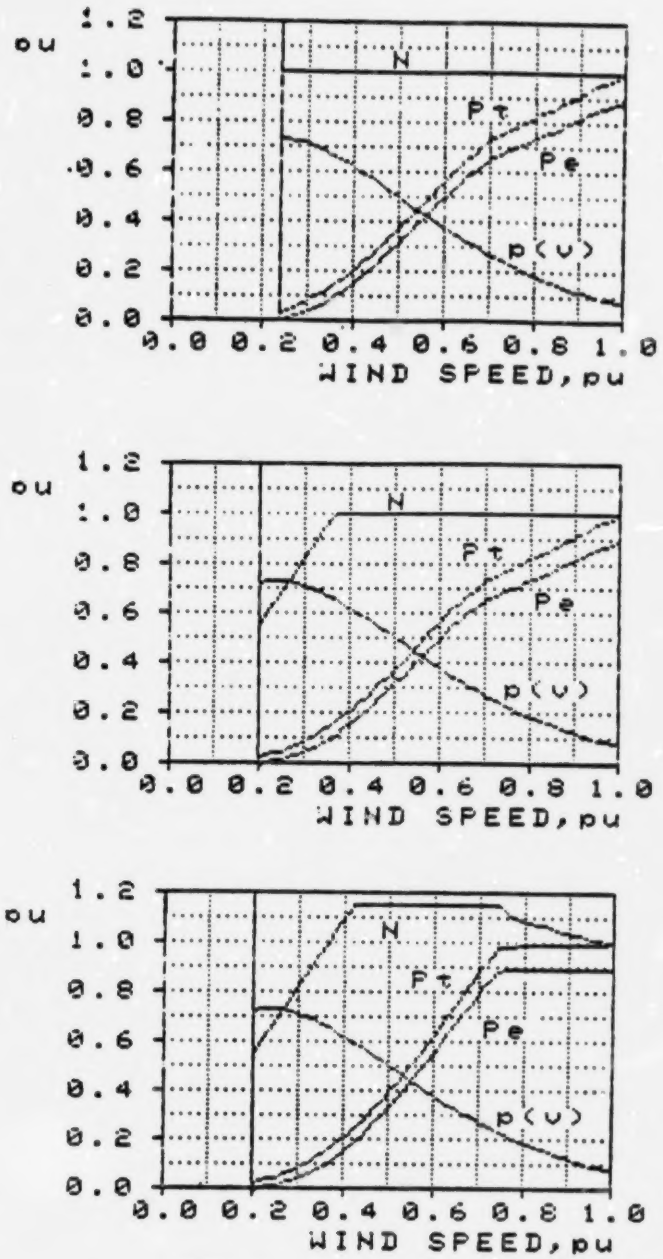
Fig. 7 - Basic Electrical Scheme.



LEGEND:

1. GENERATOR
2. GEN. FREQ. SWGR.
3. BRAKING RESISTOR
4. STATIC FREQUENCY CHANGER
5. COMMUTATING REACTOR
6. HARMONIC FILTERS
7. NETWORK FREQUENCY SWGR
8. CONTROL ROOM
9. CABLE TRAY
10. CABLE TRENCH
11. AUX TRANSFORMER
12. 600V AUX SWGR
13. EXCITATION TRANSFO
14. BATTERY ROOM

Fig. 8 - Rotor Support Building Electrical Equipment Layout.



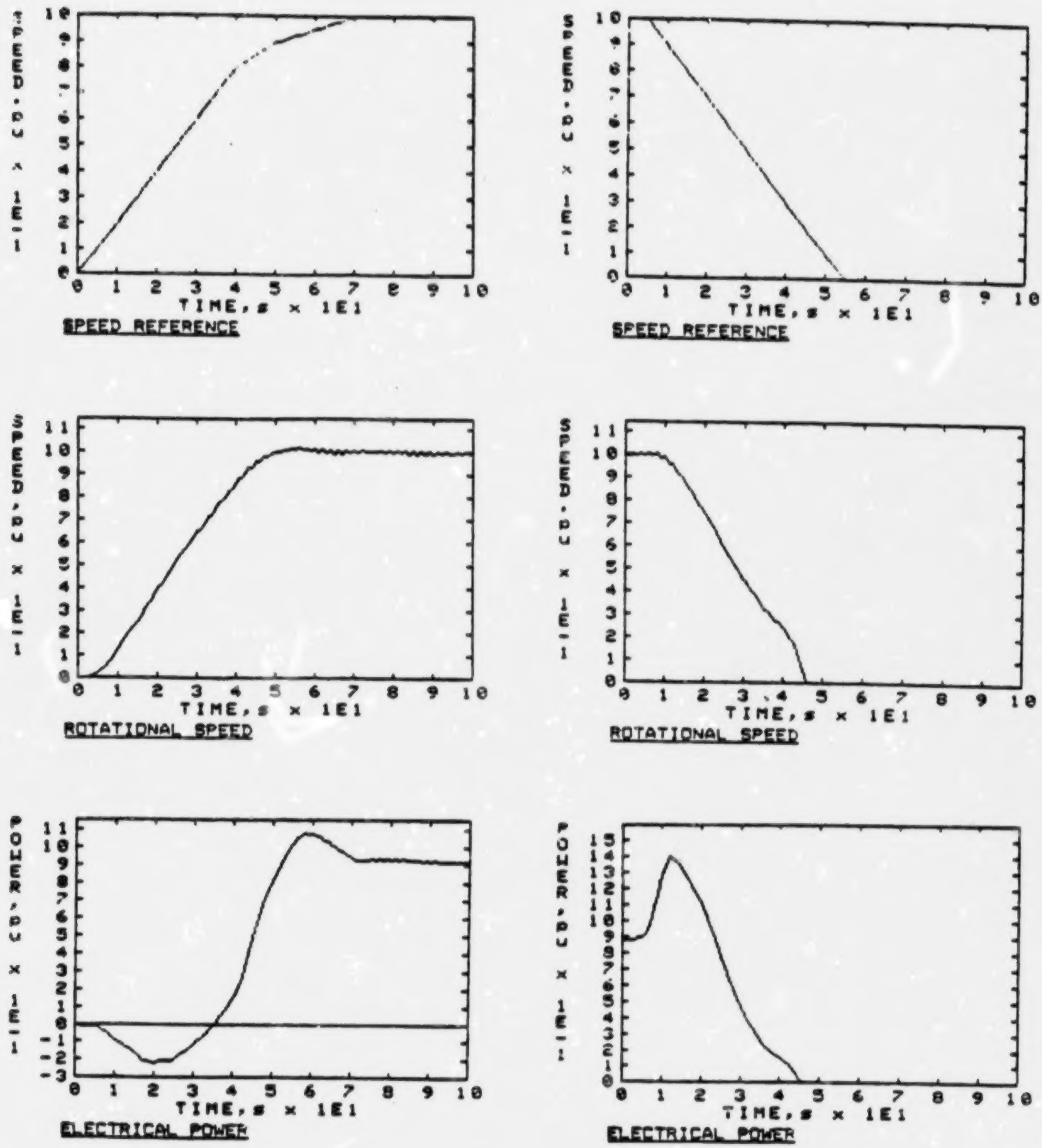
Mode A
Constant Speed

Mode B
Variable Speed

Mode C
Variable Speed
with Power Limit

KEY: N = Rotational speed (1 pu = 14.25 rpm)
Pt = Turbine shaft power (1 pu = 4 MW)
Pe = Electrical output power (1 pu = 4 MW)
p(v) = Wind speed probability density (x 0.1)
1 pu wind speed = 22.4 m/s at equator height

Fig. 9 - Performance Characteristics for the Optional Control Modes.



Starting

Electrodynamic Braking

Fig. 10 - Starting from Standstill and Electrodynamic Braking at Rated Wind Speed.

(For pu base values see Fig. 9)

FORT SEVERN WIND/DIESEL UPDATE

Per Drewes
Ontario Hydro

Background

Ontario Hydro's projects in wind energy have largely been directed towards the development of hybrid wind/diesel systems for small community power applications. Given the sensitivity of wind turbine output to average windspeeds, one should naturally seek out areas with the highest winds. Also, it is clearly advantageous to look for applications where competing electrical generation sources are extremely costly. For Ontario, this means going north to the Hudson Bay coastline where windspeeds average 5.5 to 5.8 m/s, the highest in the province, and fuel for the community diesel generating plant often costs ten times the utility's average fuel costs.

Ontario Hydro has been working with various government agencies and with wind turbine manufacturers such as Indal Technologies and Howden. Over the past ten years as a utility, our role has largely been on the electrical side of wind power. For a small diesel powered grid, the wind powered component may represent quite a large penetration of total generating capacity and maintaining control, voltage and frequency regulation, etc., becomes a very important factor in system design. Also, as the eventual operator of the wind turbines, we are naturally interested in reliability and maintainability of the machines especially given the remoteness of these installations.

Fort Severn Project

Fort Severn is a small native community of about 300 people. Located on the shores of Hudson Bay, this remote community is approximately 800 kilometres from Ontario Hydro's nearest transmission lines. Electricity is generated at the local diesel plant which went into service a year and a half ago. The station runs unattended; a programmable controller selects one of three diesel generators (85 kW, 125 kW and 175 kW) which best matches the community's electrical demand.

Because of the aforementioned criteria of high winds and high fuel costs, Fort Severn was selected as the site for a wind/diesel project. This demonstration project is jointly sponsored by Ontario Hydro, which acts as project manager, the Ontario Ministry of Energy, the Canadian Electrical Association, Energy, Mines and Resources

While this data was collected, the final modifications to the blade/hub assembly were completed by Howden at the Fort Severn site. By early July the machine was ready for its initial test runs in Fort Severn. (The wind turbine, with the original hub design, had been tested a year earlier in Scotland).

Acceptance Testing

Before any generating equipment can be connected to Ontario Hydro's system it must undergo a testing program and be accepted by the utility. As a utility, we are mainly concerned about two aspects: safety and compatibility. First, the equipment must be safe to operate. That is, it must present no hazards to our own operating staff and also the general public. Second, the generating source should not damage or result in a degradation in performance of any of Ontario Hydro's existing equipment or any of the community's connected loads. Assuming these two criteria are met, Ontario Hydro is of course also interested in optimizing the performance of the wind turbine itself.

Acceptance testing was scheduled for mid-July and was carried out by two engineers from Ontario Hydro and Howden's site engineer. The results are summarized in a report issued by the Design and Development Division of Ontario Hydro.

Initial testing of the wind turbine was carried out with the generator connected to the dump load. Controls, start-up signals, yaw drives, brakes etc., were tested before interconnection to the utility system. Proper phase rotation was also verified before the first synchronization tests.

To prepare for the first synchronization run, the utility system was set to operate with the largest diesel generator running in manual mode. With each successful synchronization of the wind turbine, the system was switched to a smaller diesel and eventually back to a completely automatic operating mode.

The 60 kW Howden wind turbine generator represents the highest known penetration of wind power on a utility system. Once the unit is synchronized with the community's mini-grid, the diesel engine and its governor are the sole means of regulating system frequency. As shown in Figure 3, the small 85 kW diesel has the hardest time controlling frequency but still meets specifications of 60± 1 Hz.

The wind turbine generator is equipped with its own voltage regulator, minimizing variation during gusty conditions. Voltage deviations were found to meet specifications of 5 percent/0.5 percent during synchronization/gusts.

All control systems were demonstrated during the testing program including shut-downs and yaw drives. During these tests the wind turbine contributed up to 75 percent of the electrical demand and produced no noticeable change to the supply of electricity from the community's standpoint. Under normal start-up conditions, the wind turbine was able to synchronize successfully with Ontario Hydro's system and operation of the machine resulted in no detrimental effects to the utility's diesel generators.

Future Work

While the synchronization tests were successful, some deficiencies and minor faults were found and will need to be corrected before acceptance of the wind turbine. For example, intermediate relays should be installed to interface with the diesel plant programmable controller and emergency stop button.

Other items to be modified include increasing the output limits setting for dump load control and refining the settings for voltage and speed to reduce synchronization time. The modifications are simply changes to the programmable controller's software. They are all part of gaining operating experience with the wind turbine and form part of the tasks to be carried out during the scheduled first month of manual operation. After this initial running period, expected to the completed by the end of October, the machine will be placed in automatic mode and left to operate on its own. A final assessment of the machine and the overall hybrid wind/diesel concept will be made after approximately two years running time.

FORT SEVERN

DAILY SUMMARY OF DIESEL AND WIND - TURBINE GENERATOR OUTPUT

Maximum Amb.Temp Deg. C	Minimum Amb. Temp. Deg. C	Maximum Wind Speed m/sec.	Minimum Wind Speed m/sec.	Maximum WTG Power kWatts	Average WTG Power kWatts	WTG ENERGY kWatthours	Diesel 1 Energy k Watthours	Diesel 2 Energy k Watthours	Diesel 3 Energy k Watthours	Community Energy Dem. k Watthours	Community Max. Demand k Watts	Community Min. Demand k Watts	Frequency Average Hertz	Frequency Variance Hertz	Date
26.37	11.12	10.52	2.50	0.00	0.00	-0.02	-0.02	914.92	190.98	1500.00	85.37	67.98	60.11	0.00	01 JUN 87
26.86	11.67	9.26	2.40	0.00	-0.00	-0.02	-0.02	1680.12	-0.04	1566.38	87.77	48.48	60.09	0.00	02 JUN 87
5.75	-1.49	8.99	2.03	0.00	-0.00	-0.02	-0.02	1682.21	-0.05	1589.94	90.01	48.98	60.10	0.00	03 JUN 87
13.55	-0.52	8.66	1.80	0.00	-0.00	-0.03	-0.02	1672.01	-0.04	1622.82	89.04	49.06	60.13	0.00	04 JUN 87
15.23	2.91	9.89	2.26	0.00	-0.00	-0.03	-0.02	1573.93	-0.04	1543.42	81.61	49.18	60.13	0.00	05 JUN 87
9.70	-2.49	8.28	0.84	0.00	-0.00	-0.02	-0.02	1504.03	-0.05	1465.04	74.35	47.93	60.14	0.00	06 JUN 87
3.01	-4.54	7.09	2.27	0.00	-0.00	-0.02	-0.02	1583.86	-0.05	1513.80	73.02	51.13	60.13	0.00	07 JUN 87
11.09	-1.53	4.65	1.59	0.00	-0.00	-0.03	-0.02	1627.40	-0.04	1523.98	81.24	45.42	60.13	0.00	08 JUN 87
19.72	-0.33	7.83	2.59	0.00	-0.00	-0.02	-0.02	1612.13	-0.05	1503.22	82.70	44.98	60.13	0.00	09 JUN 87
13.54	-0.16	7.10	1.45	0.00	-0.00	-0.03	-0.02	1496.14	60.65	1447.20	84.61	42.13	60.11	0.00	10 JUN 87
9.62	-0.63	11.04	4.86	0.00	-0.00	-0.02	-0.02	1578.25	-0.04	1469.48	76.14	42.11	60.11	0.00	11 JUN 87
5.86	-1.83	9.21	4.15	0.00	-0.00	-0.03	-0.02	1605.59	-0.05	1513.18	84.24	47.14	60.11	0.00	12 JUN 87
27.35	2.67	8.39	2.67	0.00	-0.00	-0.02	-0.02	1508.48	-0.04	1403.90	69.75	44.40	60.11	0.00	13 JUN 87
17.22	3.53	12.80	3.58	0.00	-0.00	-0.03	-0.02	1473.17	-0.05	1371.20	71.20	41.61	60.13	0.00	14 JUN 87
26.79	-0.66	7.80	0.65	0.00	-0.00	-0.03	-0.02	1534.47	-0.05	1424.68	77.49	39.96	60.12	0.00	15 JUN 87
20.50	-1.14	5.17	0.47	0.00	-0.00	-0.03	-0.03	1573.29	-0.04	1461.36	81.51	39.83	60.13	0.00	16 JUN 87
34.92	7.92	9.90	2.83	0.00	-0.00	-0.03	-0.02	1605.75	-0.05	1486.54	88.25	42.68	60.03	0.02	17 JUN 87
21.76	1.51	11.77	5.83	0.00	-0.00	-0.02	-0.02	1599.15	-0.06	1480.16	81.85	40.92	60.02	0.00	18 JUN 87
15.94	-2.73	7.33	2.64	0.00	-0.00	-0.03	-0.03	1584.88	-0.04	1490.86	91.14	41.91	60.04	0.00	19 JUN 87
24.68	1.51	6.83	2.71	0.00	-0.00	-0.03	-0.02	1512.86	-0.05	1420.86	78.52	42.64	60.03	0.00	20 JUN 87
14.38	1.55	6.23	0.89	0.00	-0.00	-0.03	-0.02	1420.53	-0.05	1335.86	66.88	42.40	59.99	0.00	21 JUN 87
13.37	1.36	8.88	4.25	0.00	-0.00	-0.03	-0.03	1465.47	40.48	1425.00	80.57	40.77	60.02	0.00	22 JUN 87
10.44	1.08	11.10	6.04	0.00	-0.00	-0.03	-0.03	1599.69	-0.04	1524.82	86.98	44.31	60.04	0.00	23 JUN 87
24.37	7.60	7.62	0.85	0.00	-0.00	-0.03	-0.02	1569.78	-0.04	1474.62	79.05	44.40	60.02	0.00	24 JUN 87
24.01	5.29	6.75	0.51	0.00	-0.00	-0.02	-0.02	1663.39	-0.04	1547.28	82.77	44.39	59.98	0.00	25 JUN 87
8.73	1.22	11.28	4.17	0.00	-0.00	-0.03	-0.09	1611.52	-0.04	1522.50	86.89	44.41	60.04	0.00	26 JUN 87
4.77	1.27	11.05	6.59	0.00	-0.00	-0.03	-0.03	1567.00	-0.05	1478.40	76.44	47.59	60.04	0.00	27 JUN 87
3.26	0.80	7.39	5.36	0.00	-0.00	-0.03	-0.03	1504.16	-0.04	1419.08	69.76	45.93	60.04	0.00	28 JUN 87
11.32	1.33	8.90	4.09	0.00	-0.00	-0.02	-0.02	1551.60	-0.04	1470.22	74.09	44.96	60.05	0.00	29 JUN 87
12.62	1.98	6.22	0.75	0.00	-0.00	0.00	-0.01	1500.00	-0.04	1400.00	68.16	43.41	60.04	0.00	30 JUN 87

AVERAGE MONTHLY WINDSPEED = 5.81 METERS/SECOND
AVERAGE MONTHLY WTG ENERGY = KWH
TOTAL MONTHLY WTG ENERGY = KWH
AVERAGE DAILY COMMUNITY ENERGY DEM. = 1479.86 KWH
TOTAL MONTHLY COMMUNITY ENERGY DEM. = 44395.80 KWH

FIGURE 1

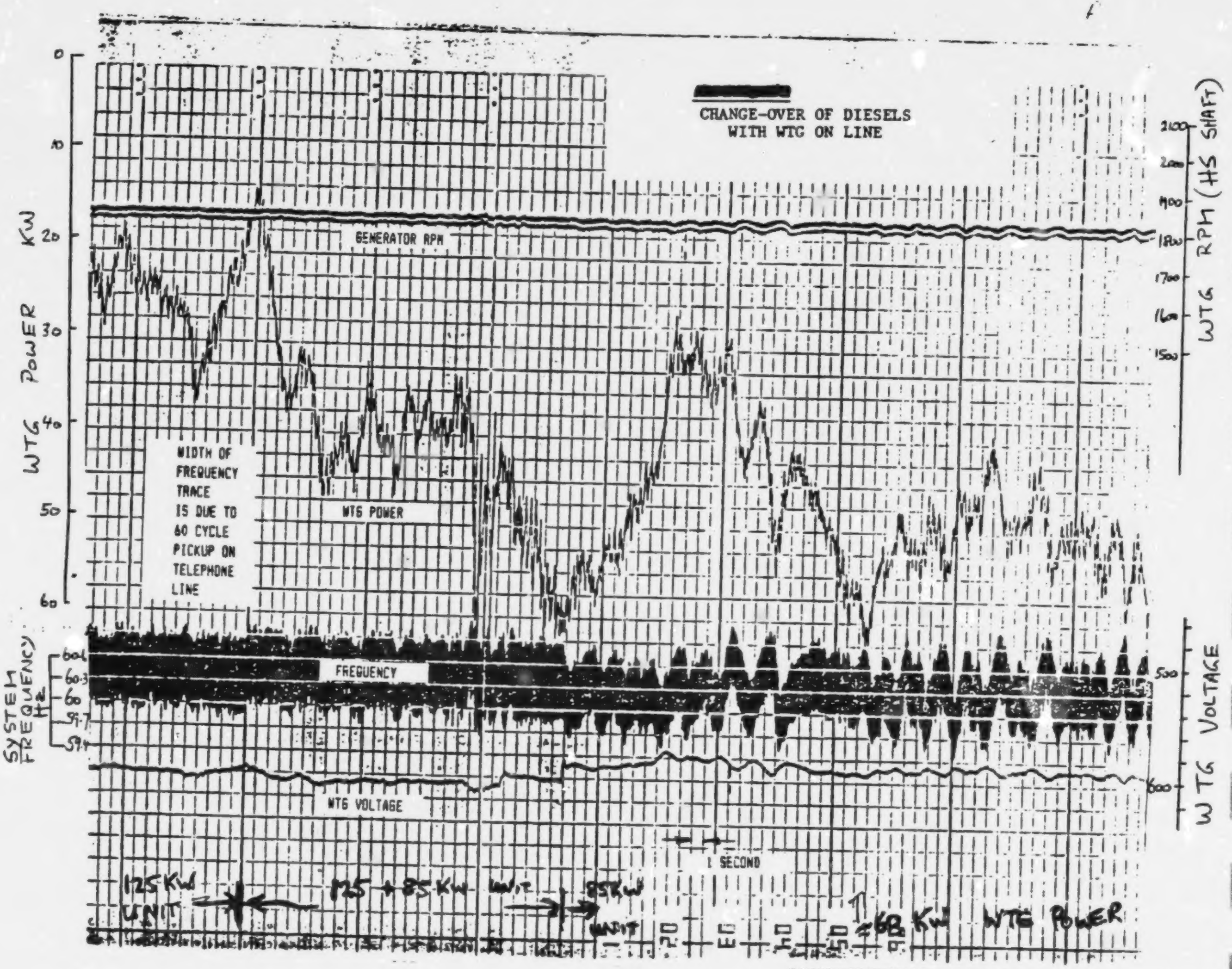
FORT SEVERN DIESEL AND WIND - TURBINE GENERATOR

ONE MINUTE INTERVAL DATA

AMBIENT TEMP DEG. C	WIND SPEED METERS/S	WTG POWER KW	D1 POWER KW	D2 POWER KW	D3 POWER KW	COMM.POWER KW	RED CURRENT AMPS	W CURRENT AMPS	B CURRENT AMPS	FREQUENCY HERTZ	FREQUENCY HERTZ	FREQUENCY HERTZ	WTG ENERGY KWH	CUMM. ENERGY KWH	DATE	TIME
11.37	10.53	-0.68	-0.00	63.24	-0.01	57.23	76.11	60.29	71.76	0.00	60.04	60.04	-0.01	0.95	24 JUL 87	09:12
11.70	15.14	-0.76	-0.00	64.43	-0.01	58.01	81.40	60.40	69.51	0.00	0.00	0.00	-0.02	1.92	24 JUL 87	09:13
11.71	8.17	-1.50	-0.00	62.14	-0.00	56.29	81.41	63.16	60.10	0.00	0.00	0.00	-0.05	2.96	24 JUL 87	09:14
11.61	13.56	-0.83	-0.00	61.03	-0.00	55.43	79.74	63.88	57.24	0.00	0.00	0.00	-0.06	3.78	24 JUL 87	09:15
11.51	11.41	-0.76	-0.00	63.91	-0.00	57.72	75.66	68.65	65.16	0.00	0.00	0.00	-0.08	4.74	24 JUL 87	09:16
11.57	11.65	-0.77	0.00	66.49	-0.00	60.50	76.80	74.87	65.20	0.00	0.00	0.00	-0.09	5.75	24 JUL 87	09:17
11.75	4.65	-0.80	0.00	68.06	-0.00	61.89	77.61	77.32	67.15	0.00	0.00	0.00	-0.10	6.78	24 JUL 87	09:18
11.91	11.89	-0.79	0.00	69.35	-0.00	63.39	72.71	82.91	71.99	0.00	0.00	0.00	-0.11	7.84	24 JUL 87	09:19
11.38	9.51	-0.81	0.00	68.39	0.00	62.28	74.57	76.30	72.58	0.00	0.00	0.00	-0.13	8.88	24 JUL 87	09:20
11.36	10.08	-0.80	-0.00	66.34	-0.01	60.93	71.47	68.71	75.08	0.00	0.00	0.00	-0.14	9.89	24 JUL 87	09:21
11.38	8.47	-0.94	-0.00	66.43	-0.00	60.43	72.82	74.39	71.02	0.00	0.00	0.00	-0.16	10.89	24 JUL 87	09:22
11.69	5.86	25.29	0.00	34.06	-0.00	31.14	36.53	39.64	35.04	60.02	60.00	59.95	0.26	11.41	24 JUL 87	09:23
11.94	7.92	40.26	0.00	28.23	0.00	25.89	31.26	26.36	33.23	60.00	60.07	60.04	0.94	11.84	24 JUL 87	09:24
11.98	11.47	31.51	-0.00	33.68	-0.00	30.17	39.31	30.40	34.29	59.98	60.06	60.02	1.46	12.34	24 JUL 87	09:25
11.93	6.19	17.87	0.00	49.49	-0.00	45.71	63.81	46.51	52.42	60.01	59.97	60.00	1.76	13.10	24 JUL 87	09:26
11.76	7.36	42.32	0.00	19.84	-0.00	16.78	24.54	24.91	10.76	60.00	60.01	60.00	2.46	13.38	24 JUL 87	09:27
11.62	7.20	41.78	0.00	26.49	0.00	22.36	33.44	20.81	22.96	60.00	60.01	60.02	3.16	13.75	24 JUL 87	09:28
11.52	9.44	55.71	18.69	0.33	0.00	17.23	21.59	15.01	20.94	59.99	59.97	60.05	4.09	14.04	24 JUL 87	09:29
11.57	11.19	43.44	31.42	0.33	-0.01	29.67	39.97	26.58	30.50	59.79	59.96	59.83	4.81	14.53	24 JUL 87	09:30
11.46	8.23	49.09	32.66	0.33	-0.00	31.83	41.72	28.26	37.35	59.77	59.82	59.83	5.63	15.96	24 JUL 87	09:31
11.47	8.23	47.56	34.25	0.00	0.00	33.26	40.52	26.97	42.19	59.95	59.91	59.94	6.42	15.62	24 JUL 87	09:32
11.50	9.06	33.37	39.29	-0.00	-0.00	38.33	52.62	35.09	40.78	59.93	59.81	59.85	6.98	16.26	24 JUL 87	09:33
11.53	8.07	39.05	46.71	0.00	0.00	44.69	62.07	42.95	44.84	59.96	59.91	59.95	7.48	17.00	24 JUL 87	09:34
11.56	10.89	49.40	38.52	-0.00	-0.00	33.80	43.33	28.20	31.94	59.80	59.85	59.95	8.16	17.57	24 JUL 87	09:35
11.63	8.96	39.88	32.34	0.00	0.00	28.25	36.15	28.76	31.67	60.00	59.80	60.16	8.82	18.04	24 JUL 87	09:36
11.36	9.89	25.91	49.47	-0.00	-0.00	39.86	51.70	40.29	44.62	59.91	59.86	59.92	9.25	18.70	24 JUL 87	09:37
11.32	8.93	32.74	23.85	-0.00	-0.01	20.75	27.17	21.70	18.92	59.80	59.91	60.00	9.80	19.05	24 JUL 87	09:38
11.36	8.77	13.04	46.21	-0.00	-0.00	45.64	58.10	52.68	51.37	60.01	59.90	59.81	10.01	19.81	24 JUL 87	09:39
11.49	7.28	9.75	52.77	0.00	0.00	51.84	61.94	63.16	59.40	59.91	59.97	60.06	10.18	20.67	24 JUL 87	09:40
11.70	9.14	29.89	33.16	0.00	0.00	29.64	42.50	28.64	34.05	59.89	59.89	59.91	10.68	21.17	24 JUL 87	09:41
11.81	9.31	23.41	37.68	0.00	-0.00	35.77	49.02	35.90	40.24	59.94	59.92	59.91	11.07	21.76	24 JUL 87	09:42
11.63	10.85	10.67	43.64	-0.00	-0.00	41.58	56.89	43.77	45.80	59.96	59.94	59.97	11.38	22.46	24 JUL 87	09:43
11.45	6.02	6.01	54.02	-0.00	-0.00	51.18	67.89	55.39	57.94	59.84	60.01	59.94	11.48	23.31	24 JUL 87	09:44
11.40	9.08	14.04	45.58	-0.00	-0.00	43.26	59.08	49.31	51.11	59.91	59.96	59.96	11.71	24.03	24 JUL 87	09:45
11.26	12.85	30.57	29.52	-0.00	-0.00	25.35	28.08	28.54	33.93	59.90	60.04	60.05	12.22	24.45	24 JUL 87	09:46
11.04	15.33	12.14	43.55	-0.00	-0.00	41.14	49.74	46.74	49.85	59.99	59.79	59.91	12.42	25.14	24 JUL 87	09:47
11.00	12.15	1.80	62.59	0.00	0.00	61.29	76.53	69.23	71.90	59.97	59.99	59.81	12.45	26.16	24 JUL 87	09:48
10.94	9.91	35.93	24.70	0.00	-0.00	18.69	26.38	19.06	23.21	59.96	59.93	59.94	13.05	26.47	24 JUL 87	09:49
10.97	10.91	31.29	25.49	-0.00	-0.00	24.27	28.54	26.91	29.16	60.09	59.86	60.00	13.57	26.87	24 JUL 87	09:50
10.94	10.37	31.84	24.47	-0.00	-0.00	22.49	22.19	28.78	29.37	57.89	60.01	60.05	14.10	27.25	24 JUL 87	09:51
10.96	10.15	22.48	34.95	0.00	0.00	32.42	34.93	38.20	44.00	59.89	59.87	59.93	14.48	27.79	24 JUL 87	09:52
11.08	9.19	37.57	23.00	-0.00	0.00	29.60	13.10	28.12	30.19	59.88	59.82	59.82	15.19	28.13	24 JUL 87	09:53
11.16	8.64	31.35	37.13	0.00	0.00	36.73	36.45	36.56	54.52	59.99	60.07	59.95	15.63	28.74	24 JUL 87	09:54
11.01	7.09	18.52	48.53	-0.00	-0.00	45.44	51.76	50.29	58.87	59.81	59.52	59.93	15.94	27.50	24 JUL 87	09:55
11.08	13.36	15.25	46.71	-0.00	-0.00	45.82	52.28	50.75	59.58	59.97	59.88	59.92	16.19	30.26	24 JUL 87	09:56
11.15	9.81	29.00	30.12	-0.00	-0.00	25.53	28.16	25.10	38.73	59.84	59.93	59.92	16.67	30.71	24 JUL 87	09:57
11.24	9.43	13.73	39.17	-0.00	-0.00	37.49	43.65	39.36	49.90	59.89	59.78	59.88	16.90	31.33	24 JUL 87	09:58

FIGURE 2

FIGURE 3



The wind turbine, operating in parallel with the medium size diesel (125 kw), is producing between 20 to 40 kw of power. The small diesel (85 kw) comes on line and the medium diesel drops out after approximately 30 seconds. Output from the wind turbine increases to the 30 to 60 kw range and with the smaller diesel, system frequency variation increases slightly.

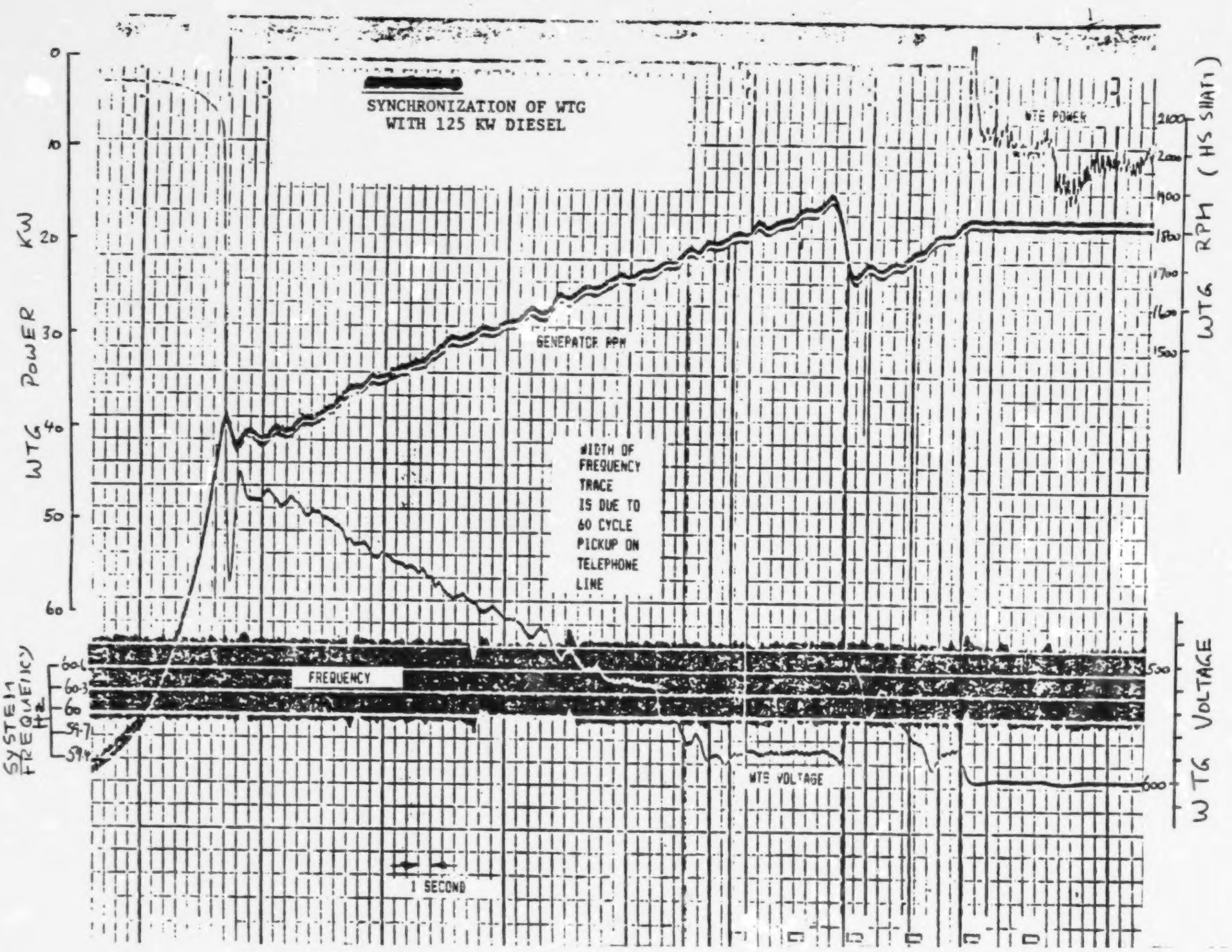
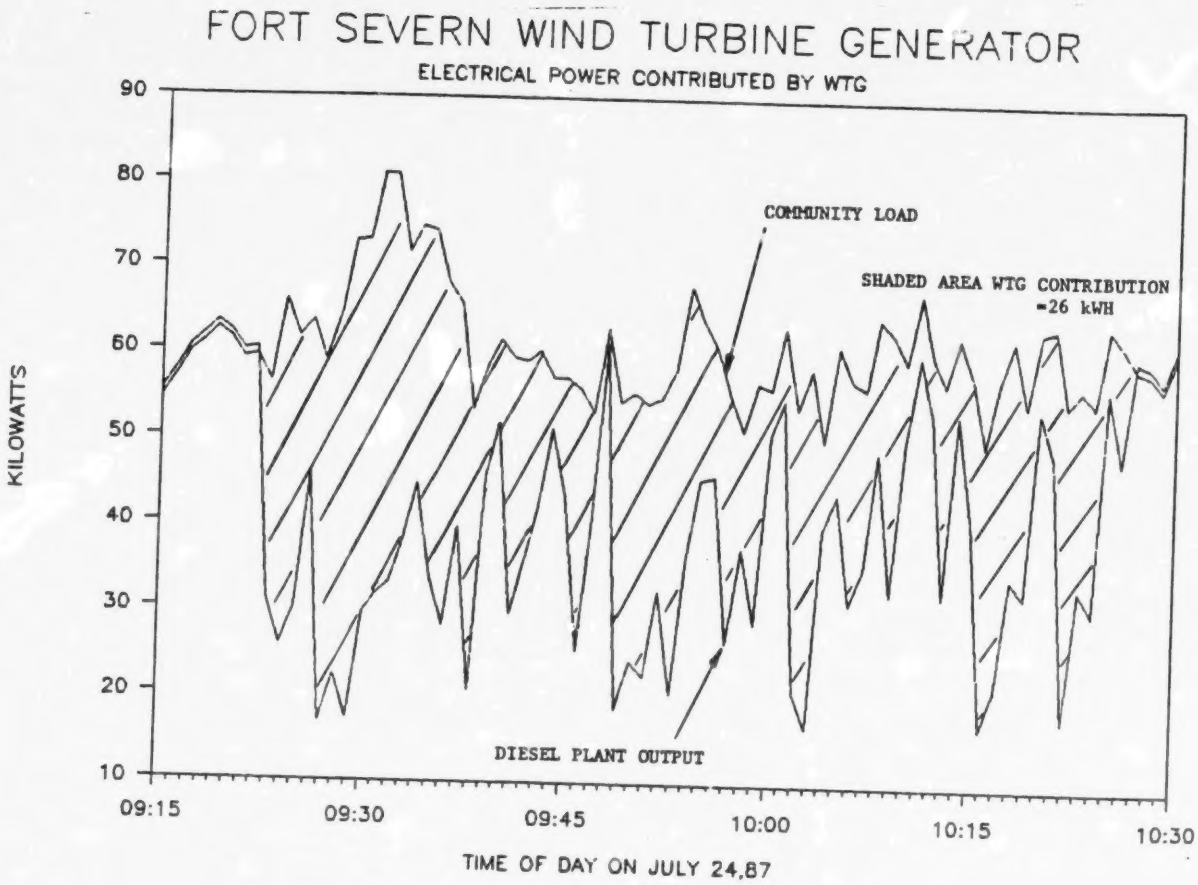


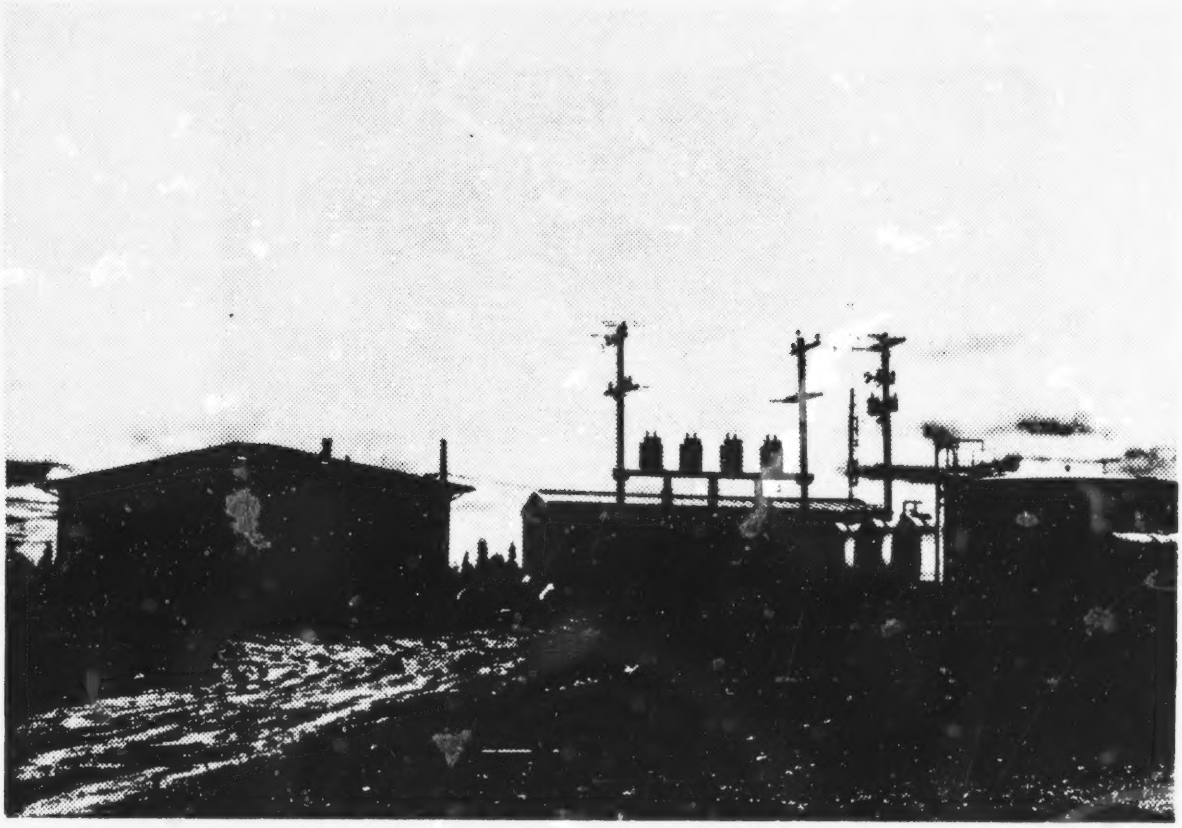
FIGURE 4

As the anemometer senses start-up wind speeds, the brakes on the wind turbine are released. The wind starts the rotor and it accelerates quickly. At 1000 rpm on the high speed shaft, excitation current is applied to the generator. At 1800 rpm, the synchronizer will lock in the turbine to the diesel powered grid if proper phase angle is met. If it fails to synchronize, the dummy load is applied at 1900 rpm to slow the wind turbine for another attempt. This start-up required two synchronization attempts.

FIGURE 5



The wind turbine generated a very high proportion of the community's electrical power during acceptance testing.



FORT SEVERN'S DIESEL PLANT (CENTRE) WENT INTO
SERVICE IN DECEMBER, 1985

Canada and Howden Group Canada Ltd. At the time of last year's CanWEA Conference, most of the installation work for a HWP60 wind turbine had been completed. A description of that work is contained in the conference proceedings.

Project Update

Over the past year, Howden has made several design changes to the hub/blade assembly of the HWP60 wind turbine as a result of some failures experienced with their larger machines in California. The Fort Severn machine therefore, stood without blades for most of the elapsed time. During that period Ontario Hydro installed a monitoring system at the Fort Severn site. We officially started our data collection program at the beginning of the year and we have been collecting windspeed data as well as information relating to community electrical demand, diesel generator operation, system voltages etc., since that time. We are using a FLUKE2280B data logger to monitor

THE 60 kW WIND TURBINE IS CAPABLE OF SUPPLYING
MOST OF FORT SEVERN'S ELECTRICAL POWER DURING WINDY PERIODS

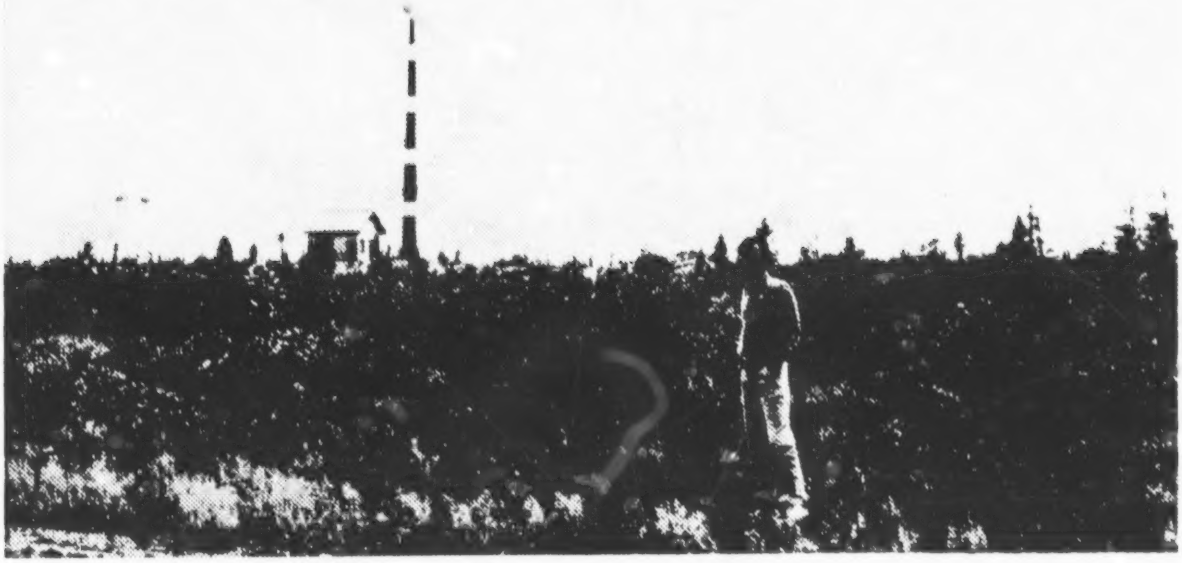
As stated earlier, the data collection program commenced at the beginning of the year. The data is analyzed and quarterly summary reports are produced. Two reports covering the first half of 1987 have been issued to date.

fourteen parameters. The tapes are retrieved on a monthly basis by the local station operator and forwarded to head office for processing on an IBM-PC. Figure 1 shows an example of the monthly summary sheet. Detailed data is available on computer discs.

We are looking at this information to get a better understanding not only of windspeeds and their patterns, but also the community's electrical demand characteristics. What are the peak loads? What are the minimum loads? Are there any patterns in the demand and more importantly are there any relationships between availability of wind power and electrical demand?

We are also interested in the stability of the system. What are the voltage fluctuations with and without the wind turbine tied to the mini-grid? Since the small diesel system is in itself a new development, Hydro's remote community engineering staff are interested in the performance data relating to the running time of each size diesel, system stability during switch-over and current balance in the three phase distribution system.

INSTALLATION OF 60 kW HOWDEN WIND TURBINE IN
FOR SEVERN WAS COMPLETED IN JULY, 1987



DEVELOPMENTS IN SWECS

AEROWATT INTERNATIONAL AUTONOMOUS WIND ENERGY POWER PLANTS:

OBSERVATIONS ON THE OVERALL EFFICIENCY OF SUCH SYSTEMS

Jean-Marc Noel
Aerowatt International

Autonomous wind energy power plants are a significant element in the product offerings of Aerowatt International. This paper gives details of the philosophy governing the use of such systems to provide power to remote communities. Concrete examples are used to illustrate how the overall efficiency of such systems may be optimized.

1. DEFINITION OF THE EQUIPMENT

In the vocabulary of Aerowatt International, the term "autonomous wind energy power plant" signifies a wind energy conversion system made up of the following components:

- One or more windgenerators which deliver current in the form of AC voltage,
- A dual conversion energy processing unit which contains:
  - one or more transformers associated with the windgenerator(s) [option A],
  - one or more rectifiers associated with the windgenerator(s),
  - measurement and control equipment,
  - an inverter,
  - an output transformer [option B],
- A battery storage bank,
- A stand-by generator set.

Such a system is used to provide a permanent source of energy to an associated distribution system in the form of AC current at 220 V rms/three-phase/50 or 60 Hz [option B: 380 or 415 V].

The stand-by generator is used only after a period of calm wind conditions of sufficient duration to completely discharge the battery storage bank.

2. PARTICULAR ASPECTS OF AEROWATT INTERNATIONAL EQUIPMENT

2.1. Consequences of the operating principle

The operating principle for autonomous wind energy power plants is that of dual conversion:

- The windgenerators deliver AC current. This current is rectified for storage in the battery bank. Such storage occurs whenever the output of the windgenerators exceeds the power demand of the "grid."
- The "grid" is permanently powered by the inverter, which operates even when the stand-by generator set is in service.

Thus, the totality of the energy drawn by the "grid" is rectified and then reconverted to AC by the inverter.

Given these operating conditions, Aerowatt International attaches a high degree of importance to the use of components whose conversion efficiency is the highest available in today's state of the art.

2.2. Particularities of Aerowatt International material

Aerowatt International uses battery banks with a high voltage rating: 272 V for installations using pseudo-sinewave inverters and 310 V for the those using sinewave inverters.

As a result, the rectification and reconversion losses, in the range of 1 to 1.5 V in constant terms, observed in the active elements (diodes, thyristors and transistors) are relatively low.

The use of such high battery bank voltages gives the following results:

- Since the windgenerators deliver their current at an rms voltage of about 220 V, the rectification of this current by a six-phase bridge will create DC voltages between 270 to 315 V. Thus, the rectifiers included in the dual conversion processing unit do not include transformers.

[Option A] - If the distance between the windgenerators and the dual conversion cabinet is long enough to provoke voltage drops, this option remedies the situation by placing high efficiency autotransformers upstream of the rectifiers and transporting the windgenerator current at 380 V.

- Since the battery storage bank uses one of the previously mentioned rated voltages, the inverter does not require a transformer to create an rms voltage of 220 V.

[Option B] - If the voltage to be delivered to the "grid" is different from 220 or 240 V, this option uses a high efficiency autotransformer to adapt the output voltage of the inverter to the value required by the "grid."

The throughput efficiencies of the various components (when operating at rated values) are as follows:

- Rectifiers: 97 to 98 %
- Inverters:
  - pseudo-sinewave: 97 %
  - sinewave: 94 to 95 %
- Autotransformers: 95 %.

It follows that the losses resulting from dual conversion, when the systems are operated at rated values, will fall between 5 and 17 %.

An extremely important element in determining the overall efficiency of an autonomous wind energy power plant is the no-load power consumption of the inverter since this unit is in service permanently, even when no power is being drawn by the "grid."

Inverters supplied to Aerowatt International specifications have very low, no-load power consumption:

< 100 W for pseudo-sinewave inverters,

< 150 W for sinewave inverters.

2.3. Choice of storage batteries

Aerowatt International has been able to research, define and have built to its specification various components of the autonomous wind energy power plant systems.

On the other hand, Aerowatt International uses storage batteries that are available on a regular, commercial basis.

Experience and consultations with battery manufacturers have shown that the type of storage battery best adapted to the type of use required by autonomous wind energy power plants is the stationary lead-acid battery with positive, tubular plates.

The typical energy charge/discharge efficiency of this type of battery cell is about 80 %.

This efficiency is applicable only to that part of the power plant energy that actually transits the battery; i.e., the fraction of the total energy which exceeds the demand of the "grid" at a given moment.

Aerowatt International uses charge/discharge losses of 10 to 20 % when determining the optimum size for the battery bank in an autonomous wind energy power plant. The actual value used will depend on:

- the wind regime at the customer site, with regular wind regimes, such as those found in trade wind areas, being the most favorable,

- the type of utilization; e.g., if there is a high, daily modulation of "grid" load, there will be higher charge/discharge losses than if the "grid" load remains relatively stable.

3. SCOPE OF APPLICATION

The analysis leading to the adequate sizing of an autonomous wind energy power plant can be approached in the following way:

- What is the average amount of energy required on a daily basis?
- What is the maximum, instantaneous load on the "grid," and what type of equipment is generating the load?
- What is the wind resource at the site being considered?

3.1. Energy distributed on a daily basis

The average energy distributed on a daily basis is the parameter which is used to calculate the capacity of the battery storage bank. In order that the battery bank might have a normal service life, its size must be at least sufficient to assure an energy supply to the power plant during a 24 hour period of 'no-wind' conditions.

As an example, a battery storage bank made up of 135 lead-acid, positive tubular plate cells, with C10 (10 hour discharge) capacities of 1000 Ah each, can deliver 216 kWh (80 % of the C10 capacity) 1000 times. Such a battery storage bank has a total weight of nearly 10 metric tons.

The on-site cost of such a battery bank depends, of course, on the purchase price as well as transportation costs (which can vary considerably). Aerowatt International's experience has shown that a battery of the size cited above is about as large as can be successfully proposed in today's market.

3.2. Maximum power and type of load

The maximum power demanded by the "grid" as well as the type of equipment making up the load determine the specifications of the inverter to be used.

For its autonomous wind energy power plants, Aerowatt International uses inverters with the following characteristics:

- 10 kW rated power with a power factor of .8; an overload of 50 % can be tolerated for several minutes,
- 25 kW rated power with a power factor of .8; similar overload constraints apply.

Pseudo-sinewave inverters are used whenever part of the load is made up of asynchronous motors whose power rating approaches the rated power of the inverter. Such inverters are equipped with an electronic circuit which creates a ramp within which the current is constant (voltage and frequency may vary) when the current demanded by the "grid" is high (start-up of the inverter or start-up of a motor when the inverter is already in service). As a result, these inverters can start-up motors of relatively high power ratings.

Output voltage of this type of inverter is pseudo-sinewave, in the sense that of the odd harmonics only the 3rd to the 19th have been suppressed. As a result, the power ratings of asychronous motors are downgraded 10 % to limit overheating.

Sinewave inverters (harmonics < 10 %) are selected whenever the level of radio-electric interference is a significant factor. The filtering associated with the output of this type of inverter suppresses the majority of the radio-electric interference caused of the switching of strong currents with rising fronts. As a result, this type of inverter operates at a fixed frequency and can only start motors whose power rating is not superior to 20 % that of the inverter.

Neither type of inverter supplies a stable output voltage. Given the excellent efficiency of these inverters, the output voltage varies only insignificantly as a function of the load. The variations in output voltage represent more or less exactly the voltage of the storage battery. These will be +/- 10 % relative to the rated voltage of 2 V per cell. Battery voltage at full charge should be about 2.2 V per cell; voltage at 80 % discharge should be about 1.85 V per cell.

3.3. Wind resource

Considering the overall efficiency presented in Section 2, the number of windgenerators needed to provide the required energy is determined by considering the wind resource at the site and the predicted energy yield of the windgenerator/tower ensembles to be used.

- Windgenerators

  The average power outputs of the various Aerowatt International windgenerators which can be used in autonomous wind energy power plants are given in the Appendix for the entire range of wind regimes which can be encountered around the world.

- Towers

  Aerowatt International uses a variety of tower heights with its windgenerators. The most common heights are 12, 18, 24 and 30 meters.

  A simple and generally applicable rule for determining the gain in wind speed as a function of tower height relative to the wind speed measured at the standard height of 10 meters is to use the following multipliers:

Tower height (meters)	12	18	24	30
Wind speed multiplier	1	1.09	1.14	1.18

The number of windgenerators determined in this way permits selection of the proper model dual conversion energy processing unit available in the Aerowatt International product line. The models currently available can handle from 1 to 4 windgenerators.

4. FUTURE DEVELOPMENTS

Aerowatt International aims to extend the applicability of its autonomous wind energy power plants in two main directions:

4.1. Increase the maximum available power

At present, the maximum power is limited to 35 kW (for a few minutes). This limitation can be overcome by dividing the "grid" into "sub-grids" whose individual loads will remain inferior to the above-mentioned limit. If total "grid" loads are periodic, it may be possible to switch between and among inverters to limit losses.

A simpler solution will come from the development of low loss inverters with power ratings in the range of 50 kW.

4.2. Develop new windgenerators

The aim is to develop windgenerators which can yield the same amounts of energy as currently available machines but at significantly lower wind resource levels.

A new Aerowatt windgenerator, the UM100 (Vms40), is now finishing its inauguration tests. Performance characteristics for this machine have been included in the Appendix along with those of the UM70 machine.

Considering that the price of the new machine will be only about 15 % higher than that of the UM70 machine, a comparison of the energy yields of the two windgenerators shows that the new machine will yield more energy in weak wind regimes. This will geographically extend the area in which autonomous wind energy power plants can be economically used.

5. RESULTS FROM TWO SITES: TROMELIN AND EUROPA

Aerowatt International has marketed autonomous wind energy power plants for a number of years and is able to present the operating results for several systems.

Two such systems are operating on the Indian Ocean islands of Tromelin and Europa. A map of the southwestern section of the Indian Ocean has been included in the Appendix to permit precise location of these islands.

5.1. Tromelin project

Situation before the installation of the wind energy power plant

The island of Tromelin is used as an outpost of the French Meteorogical service. The outpost has a permanent staff of five technicians. Their domestic and professional energy requirements were supplied by a small diesel generator power plant equipped with 3 diesel generators, each rated at 10 kW, delivering their current at 220 V/50 Hz single-phase.

Only one generator set was operated at any given time and the supply of electricity was limited to 12 hours/day. Fuel use was about 5 liters/hour, giving an annual fuel consumption of about 22,000 liters. Since access to the island by sea is highly irregular, the diesel fuel was flown in from Reunion Island.

The local wind regime can be described as follows:

- annual average wind speed at 10 meters ------- 6.3 m/s

- Weibull's Law shape factor ------------------- c = 4

Present situation

The island of Tromelin is now equipped with the prototype of the autonomous wind energy power plant. This system includes:

- Two Aerowatt 4100 FP7 windgenerators, fitted with rotors of 9.2 meters diameter and 5kW generators. Each windgenerator is installed on a 15 meter tower.

- One CEA/2/10/380(50), dual conversion energy processing unit. This unit is fitted with a 10 kW, pseudo-sinewave inverter and an adapting output autotransformer.

- A battery storage bank made up of 120 C 500 P7 cells, each with a C10 capacity of 500 Ah. These cells, delivered in 1981, were made with thick, flat positive plates.

Considering the prototype nature of the installation, the stand-by diesel generator set, when used, powers the "grid" directly and does not recharge the battery.

Results - December 1, 1986 thru August 17, 1987

E(grd), [energy delivered to the "grid" by the autonomous wind energy power plant] ---- 6,330 kWh

E(wnd), [energy delivered to the wind energy power plant by the windgenerators] --------- 9,199 kWh

T(sds), [operating time of stand-by diesel set] ---- 252 hrs

UM, [battery voltage at end of charge] --------- 265 V

From these results it is possible to conclude the following:

$\bar{P}$(grd), [average power demanded by the "grid"] ----- 1.018 kW

e(wep), [overall conversion efficiency of the autonomous wind energy power plant] ---- 0.688

e(sds), [conversion efficiency of the stand-by diesel set expressed in kWh/liter of fuel] - 0.204

(The conversion efficiency for the stand-by diesel set is given assuming that it was delivering only the average load of 1.018 kW during its hours of operation.)

Results - April 29, 1985 thru December 1, 1986

E(grd)	10,445 kWh
E(wnd)	24,173 kWh
T(sds)	447 hrs
UM	290 V

From these results it is possible to conclude the following:

$\bar{P}$(grd)	0.749 kW
e(wep)	0.432
e(sds)	0.150

Comments

From the values given above, it is possible to draw the following lessons:

- The influence of the value chosen as the end of charge voltage for the battery storage bank is significant. The effect of changing the end of charge voltage from 290 V (2.417 V/cell) to 265 V (2.210 V/cell) improved the global wind energy conversion efficiency from 0.432 to 0.688. The latter figure is close to the projected value.

- The staff of the weather station has become accustomed to using more energy due to the fact that energy is now available on a permanent basis. The average power drawn by the "grid" from 0.749 kW during the earlier period to 1.018 kW during the latter period. This represents in increase of of 36 %.

- Since, during the time when it is operating, the stand-by diesel generator set operates with almost no load, its fuel conversion efficiency is poor.

Optimization of the system

The operation of the autonomous wind energy power plant at Tromelin can be improved along two main lines:

- Given the nature of the local wind regime, the 2 windgenerators installed at the site should provide about 50,000 kWh/year. Using the efficiency observed after adjustment of the end of charge voltage, the wind energy power plant could provide about

34,400 kWh to the "grid." Recently, the weather station has ordered a sea water desalination system. This will increase the use of wind energy on the island. Presently, when the battery bank is fully charged, available wind energy is wasted.

- The conversion efficiency of the stand-by diesel set can be improved by running its output current through a rectifier to charge the battery. This would permit the diesel set to be operated at full power. Such a modification should permit a four-fold improvement in fuel economy.

5.2. Europa project

Situation before the installation of the wind energy power plant

Europa is an island located in the Mozambique Channel. This island is used as a military outpost and a weather station. The permanent population of this island is about 15. The domestic and professional energy needs were met by two separate diesel power plants, each equipped with two, 7.5 kVA diesel generators.

The two power plants were operated on a discontinuous basis between 10 and 15 hours/day. The total fuel consumption of these power plants averaged about 30 liters/day, or 22,000 liters/year. The fuel, as well as any heavy equipment, was transported to the island once a year by naval vessels.

The annual average wind speed on Europa, measured at 10 meters above ground level, is 4.3 meters/second. The Weibull's Law shape factor is unknown.

Project definition

- Average daily energy requirement --------------------- 75 kWh
- Maximum instantaneous "grid" load -------------------- 15 kVA
- Battery capacity ------------------------------------ 48 hrs

Aerowatt International system for Europa

Using the above criteria , Aerowatt International proposed the following equipment for the Europa wind energy power plant.

- Three Aerowatt UM 70 windgenerators, each equipped with 5 kW generators and installed on 30 meter towers.
- One AW/CEA/3/25 dual conversion energy processing unit.
- One 25 kVA, 220/380 V, output autotransformer.
- A battery storage bank made up of 135 TSE 750 cells, each with a C10 capacity of 750 Ah, giving a useable energy storage in the batteries of about 162 kWh.

The projected, overall efficiency was calculated to be 80 %.

The above described equipment was ordered and has been delivered.

Technical responsibility for installation and maintenance of the autonomous wind energy power plant was assigned to the Regional Meteorological Service of Reunion Island. A new diesel generator set, rated output of 12 kVA at 220 V three-phase, was acquired to serve as a stand-by. This diesel generator set is used to charge the batteries using the rectification circuit of one of the windgenerators.

Early results

April 20, 1987 thru August 17, 1987

E(grd) -- 5,100 kWh

E(wnd) -- 6,442 kWh

E(sds), [energy delivered by the stand-by gen set] - 366 kWh

V(dsl), [volume of diesel fuel consumed] ----------- 450 ltr

UM -- 300 V

From these results it is possible to conclude the following:

$\overline{P}$(grd) -- 2.388 kW

e(wep) -- 0.79

The average, daily energy consumption during this period was 57.31 kWh.

Comments

While it is too soon to draw any definitive conclusions using only a few months of operating results, it is possible to see already that the results are close to predicted levels:

- Using the experience gained at the Tromelin site, an end of charge voltage of 2.22 V/cell was used from the outset for the Europa installation. As a result, the overall efficiency of the wind energy power plant is already within 1 % of the projected value.

- The operation of the stand-by diesel generator to charge the battery during prolonged period of calm wind conditions led to a fuel consumption of 450 liters for 366 kWh of energy, giving a fuel conversion efficiency of 0.80 kWh/liter. While this is far from optimum, it is greatly superior to the situation on

Tromelin. A modification of the alternator voltage setting of the diesel generator should yield an improvement in efficiency to at least 2.5 kWh/liter.

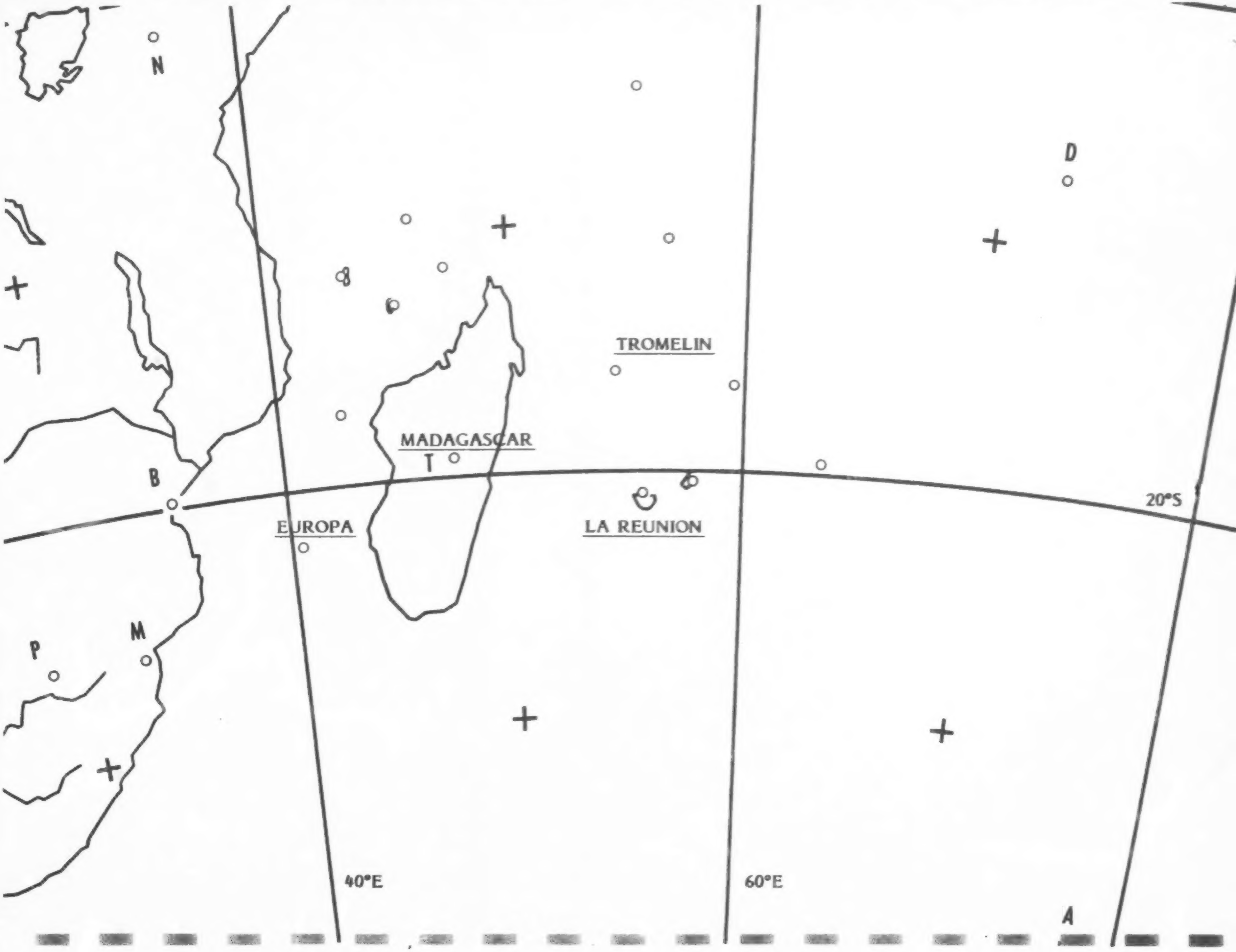
- The autonomy provided by the battery bank has been observed to be equal to three days; i.e., including inverter/transformer losses, the battery delivered 186.5 kWh.

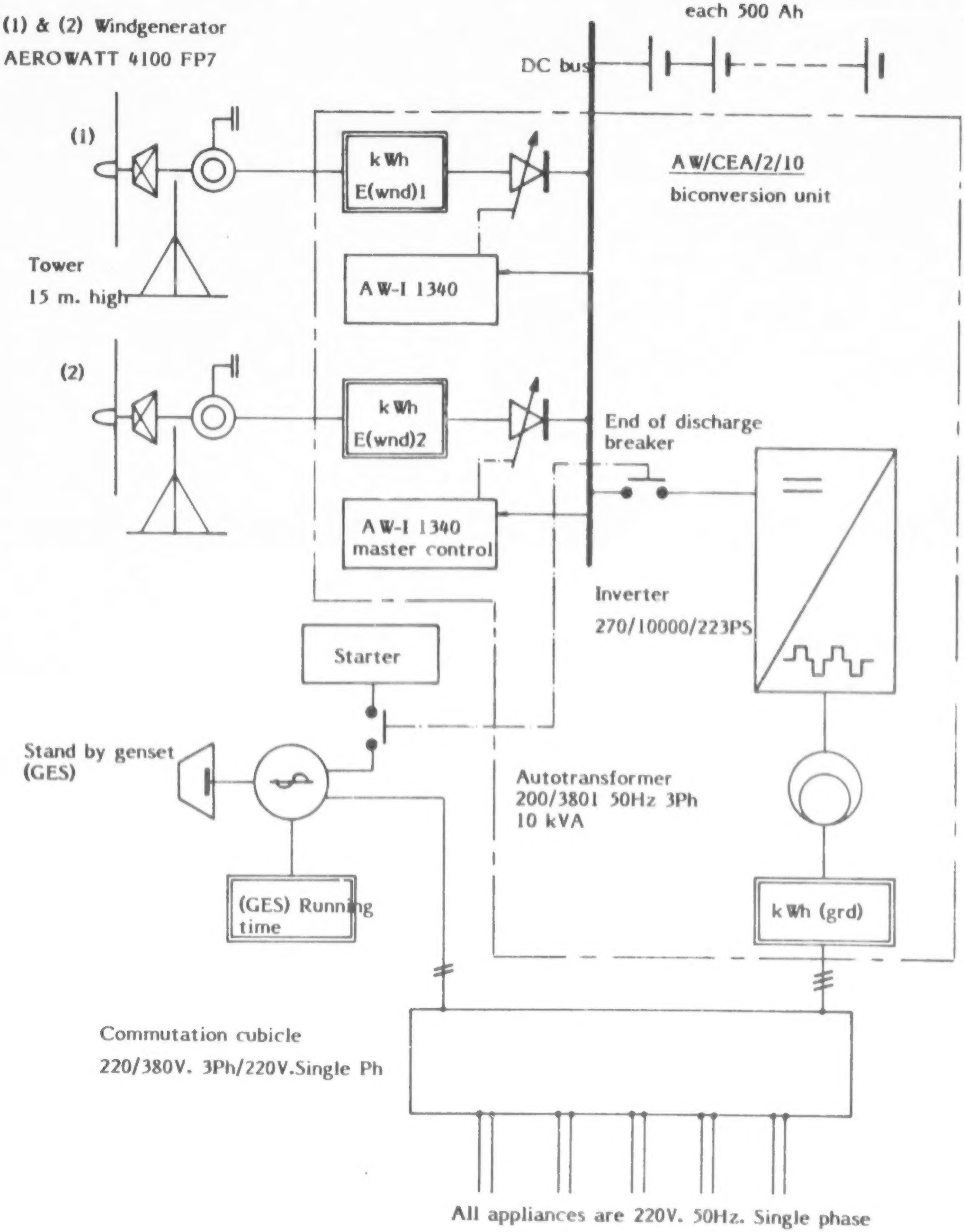
These results are nevertheless satisfactory and indicate that the projected levels of performance can be reached and even surpassed before the end of the 6 to 12 month break-in period.

6. CONCLUSION

The results presented in this paper show that the choice of technologies used by Aerowatt International in creating wind energy systems for the distribution of energy in remote areas lead the high levels of operating efficiencies.

Such high levels of efficiency, coupled with the improved performance characteristics of the new generation of Aerowatt International windgenerators, lead to a reduced investment for the same quantity of energy available to the remote site "grid."


N
D
TROMELIN
MADAGASCAR
T
B
EUROPA
LA REUNION
20°S
M
P
40°E
60°E
A


(1) & (2) Windgenerator
AEROWATT 4100 FP7
each 500 Ah
DC bus
(1)
kWh
E(wnd)1
AW/CEA/2/10
biconversion unit
Tower
15 m. high
AW-I 1340
(2)
kWh
E(wnd)2
End of discharge
breaker
AW-I 1340
master control
Inverter
270/10000/223PS
Starter
Stand by genset
(GES)
Autotransformer
200/3801 50Hz 3Ph
10 kVA
(GES) Running time
kWh (grd)
Commutation cubicle
220/380V. 3Ph/220V.Single Ph
All appliances are 220V. 50Hz. Single phase

TROMELIN - AUTONOMOUS POWER PLANT

T. A.W. 87.09.25

4100FP7H windgenerator

Turbine : 4100FP7
Airfoil : GOTTINGEN 548
Governor : 4100FP7H
Gearbox : 4100FP7 1500 rpm
Generator : LS 132 Battery

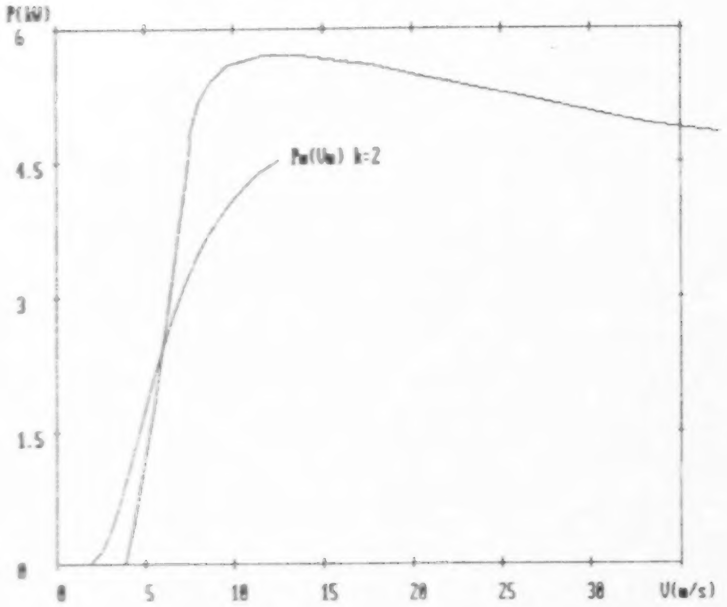
P(V) :

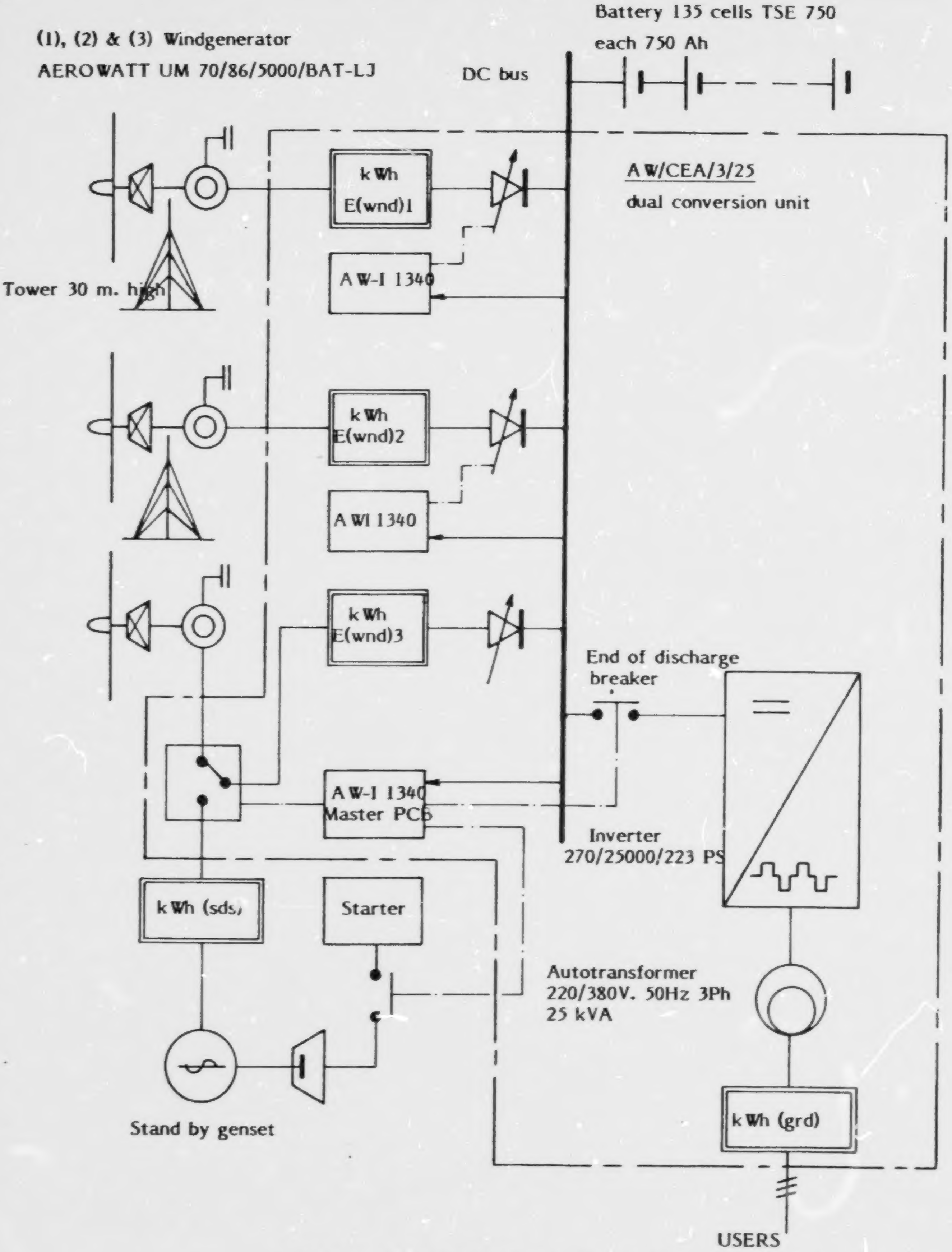
V (m/s)	P (kW)	V (m/s)	P (kW)	V (m/s)	P (kW)
0.5	+0.000	10.5	+5.739	20.5	+5.591
1.0	+0.000	11.0	+5.763	21.0	+5.569
1.5	+0.000	11.5	+5.787	21.5	+5.548
2.0	+0.000	12.0	+5.811	22.0	+5.526
2.5	+0.000	12.5	+5.819	22.5	+5.504
3.0	+0.000	13.0	+5.819	23.0	+5.483
3.5	+0.000	13.5	+5.814	23.5	+5.462
4.0	+0.244	14.0	+5.801	24.0	+5.441
4.5	+0.666	14.5	+5.788	24.5	+5.421
5.0	+1.155	15.0	+5.775	25.0	+5.400
5.5	+1.710	15.5	+5.762	25.5	+5.380
6.0	+2.334	16.0	+5.749	26.0	+5.358
6.5	+3.011	16.5	+5.736	26.5	+5.336
7.0	+3.724	17.0	+5.723	27.0	+5.313
7.5	+4.446	17.5	+5.710	27.5	+5.291
8.0	+5.197	18.0	+5.692	28.0	+5.269
8.5	+5.419	18.5	+5.672	28.5	+5.248
9.0	+5.564	19.0	+5.652	29.0	+5.228
9.5	+5.654	19.5	+5.632	29.5	+5.209
10.0	+5.714	20.0	+5.611	30.0	+5.189

YEARLY PRODUCTION FOR WEIBULL'S DISTRIBUTIONS

	k=2		k=3		k=4	
Γ(1+1/k)	0.886227		0.892979		0.906403	
V (m/s)	Pm (kW)	Ea (kWh)	Pm (kW)	Ea (kWh)	Pm (kW)	Ea (kWh)
2.0	0.040	352	0.004	35	0.000	2
2.5	0.155	1359	0.045	391	0.014	118
3.0	0.366	3210	0.172	1503	0.093	811
3.5	0.662	5800	0.406	3560	0.283	2476
4.0	1.014	8879	0.743	6508	0.589	5157
4.5	1.390	12177	1.159	10152	0.995	8720
5.0	1.767	15478	1.621	14198	1.480	12967
5.5	2.127	18636	2.093	18333	2.010	17604
6.0	2.463	21573	2.546	22306	2.543	22276
6.5	2.768	24251	2.963	25959	3.045	26673
7.0	3.044	26664	3.336	29221	3.493	30602
7.5	3.290	28820	3.662	32076	3.880	33989
8.0	3.509	30737	3.943	34542	4.206	36843
8.5	3.703	32435	4.184	36655	4.476	39212
9.0	3.874	33935	4.390	38456	4.699	41161
9.5	4.025	35259	4.565	39986	4.881	42756
10.0	4.158	36422	4.713	41282	5.029	44055
10.5	4.274	37440	4.838	42379	5.150	45111
11.0	4.375	38327	4.944	43306	5.247	45966
11.5	4.463	39094	5.033	44088	5.326	46656
12.0	4.538	39750	5.108	44746	5.389	47211
12.5	4.601	40304	5.171	45297	5.440	47653

CURVES P(V) and Pm(Vm) (Weibull's shape, k = 2)




(1), (2) & (3) Windgenerator
AEROWATT UM 70/86/5000/BAT-LJ
DC bus
Battery 135 cells TSE 750
each 750 Ah
A W/CEA/3/25
dual conversion unit
k Wh
E(wnd)1
A W-I 1340
Tower 30 m. high
k Wh
E(wnd)2
A WI 1340
k Wh
E(wnd)3
End of discharge
breaker
A W-I 1340
Master PCB
Inverter
270/25000/223 PS
k Wh (sds)
Starter
Autotransformer
220/380V. 50Hz 3Ph
25 kVA
Stand by genset
k Wh (grd)
USERS

EUROPA - AUTONOMOUS POWER PLANT

UM 70/ 5000/BAT-LJ windgenerator

Turbine : UM 70 NACA 23021 LEJELOUX BLADES
Airfoil : NACA 23021
Governor : UM 70 GOTTINGEN - Spring (5 kW) - Ratio 1/8
Gearbox : GT5 - Ratio 1/8
Generator : LS 132-S

P(V) :

V (m/s)	P (kW)	V (m/s)	P (kW)	V (m/s)	P (kW)
0.5	+0.000	10.5	+5.876	20.5	+0.000
1.0	+0.000	11.0	+5.863	21.0	+0.000
1.5	+0.000	11.5	+5.832	21.5	+0.000
2.0	+0.000	12.0	+5.801	22.0	+0.000
2.5	+0.000	12.5	+5.771	22.5	+0.000
3.0	+0.000	13.0	+5.742	23.0	+0.000
3.5	+0.000	13.5	+5.714	23.5	+0.000
4.0	+0.000	14.0	+5.686	24.0	+0.000
4.5	+0.211	14.5	+5.659	24.5	+0.000
5.0	+0.568	15.0	+5.633	25.0	+0.000
5.5	+0.981	15.5	+5.607	25.5	+0.000
6.0	+1.464	16.0	+5.582	26.0	+0.000
6.5	+2.002	16.5	+5.557	26.5	+0.000
7.0	+2.593	17.0	+5.532	27.0	+0.000
7.5	+3.248	17.5	+5.508	27.5	+0.000
8.0	+3.909	18.0	+5.484	28.0	+0.000
8.5	+4.581	18.5	+5.461	28.5	+0.000
9.0	+5.249	19.0	+5.438	29.0	+0.000
9.5	+5.876	19.5	+0.000	29.5	+0.000
10.0	+5.876	20.0	+0.000	30.0	+0.000

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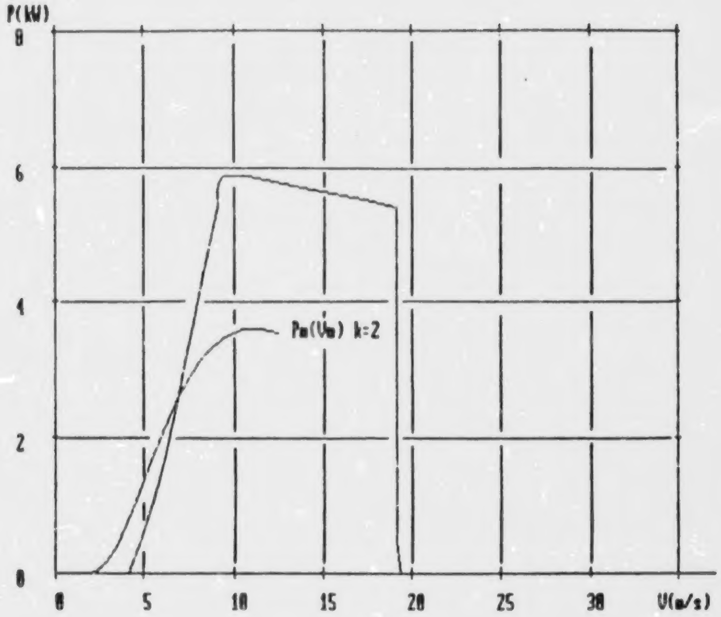
V (m/s)	Pm (kW)	Ea (kWh)	Pm (kW)	Ea (kWh)	Pm (kW)	Ea (kWh)
2.0	0.015	127	0.000	4	0.000	0
2.5	0.074	645	0.012	103	0.002	13
3.0	0.204	1789	0.067	589	0.024	212
3.5	0.413	3614	0.198	1738	0.110	967
4.0	0.687	6021	0.417	3650	0.287	2518
4.5	1.007	8824	0.718	6291	0.558	4885
5.0	1.349	11817	1.089	9537	0.912	7993
5.5	1.693	14827	1.506	13189	1.338	11722
6.0	2.023	17724	1.941	17006	1.815	15896
6.5	2.331	20421	2.370	20765	2.313	20266
7.0	2.609	22856	2.774	24302	2.803	24554
7.5	2.853	24994	3.141	27517	3.257	28533
8.0	3.061	26814	3.467	30368	3.660	32063
8.5	3.232	28310	3.749	32844	4.006	35090
9.0	3.366	29490	3.990	34952	4.295	37625
9.5	3.467	30369	4.189	36696	4.533	39710
10.0	3.536	30973	4.347	38077	4.726	41401
10.5	3.576	31329	4.463	39092	4.880	42744
11.0	3.592	31468	4.537	39742	4.997	43770
11.5	3.587	31419	4.570	40035	5.077	44478
12.0	3.563	31212	4.565	39992	5.120	44847
12.5	3.524	30873	4.525	39643	5.120	44854

CURVES P(V) and Pm(Vm) (Weibull's shape factor, k = 2)



Nota : Powers and energies are given for D.C output. They can slightly vary according the battery voltage.

T-AV 87.09.25

UM 100(Vms 40) windgenerator

Turbine : UM 100 Blades Type AW
Airfoil : NACA 23021
Governor : UM 100(Vms 40)
Gearbox : GT5 Ratio 1/8
Generator : LS 160L 6poles

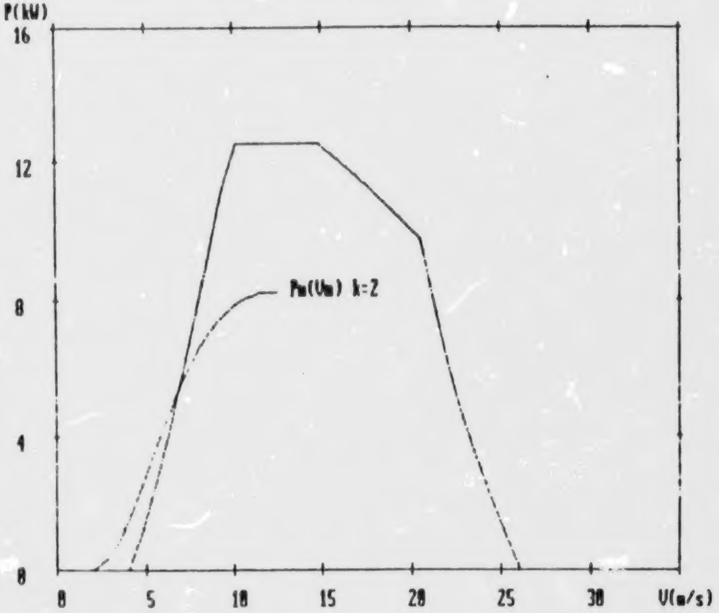
P(V) :

V (m/s)	P (kW)	V (m/s)	P (kW)	V (m/s)	P (kW)
0.5	+0.000	10.5	+12.526	20.5	+9.842
1.0	+0.000	11.0	+12.526	21.0	+8.640
1.5	+0.000	11.5	+12.526	21.5	+7.435
2.0	+0.000	12.0	+12.526	22.0	+6.318
2.5	+0.000	12.5	+12.526	22.5	+5.269
3.0	+0.000	13.0	+12.526	23.0	+4.386
3.5	+0.000	13.5	+12.526	23.5	+3.592
4.0	+0.000	14.0	+12.526	24.0	+2.834
4.5	+0.723	14.5	+12.526	24.5	+2.102
5.0	+1.544	15.0	+12.469	25.0	+1.414
5.5	+2.467	15.5	+12.241	25.5	+0.764
6.0	+3.480	16.0	+12.013	26.0	+0.137
6.5	+4.529	16.5	+11.785	26.5	+0.000
7.0	+5.652	17.0	+11.557	27.0	+0.000
7.5	+6.785	17.5	+11.329	27.5	+0.000
8.0	+7.920	18.0	+11.095	28.0	+0.000
8.5	+9.091	18.5	+10.845	28.5	+0.000
9.0	+10.261	19.0	+10.594	29.0	+0.000
9.5	+11.381	19.5	+10.343	29.5	+0.000
10.0	+12.197	20.0	+10.093	30.0	+0.000

YEARLY PRODUCTION FOR WEIBULL'S DISTRIBUTIONS

	k=2		k=3		k=4	
Γ(1+1/k)	0.886227		0.892979		0.906403	
V (m/s)	Pm (kW)	Ea (kWh)	Pm (kW)	Ea (kWh)	Pm (kW)	Ea (kWh)
2.0	0.040	353	0.001	13	0.000	0
2.5	0.189	1654	0.035	308	0.005	44
3.0	0.493	4315	0.185	1623	0.073	643
3.5	0.950	8325	0.510	4470	0.308	2698
4.0	1.533	13429	1.012	8862	0.746	6538
4.5	2.199	19266	1.663	14568	1.366	11964
5.0	2.907	25465	2.430	21283	2.127	18635
5.5	3.620	31710	3.271	28658	2.995	26234
6.0	4.311	37763	4.146	36320	3.934	34464
6.5	4.961	43462	5.013	43911	4.908	42991
7.0	5.560	48703	5.839	51148	5.872	51435
7.5	6.099	53428	6.602	57835	6.785	59436
8.0	6.576	57606	7.291	63868	7.618	66732
8.5	6.989	61226	7.900	69204	8.354	73181
9.0	7.339	64291	8.430	73843	8.989	78745
9.5	7.628	66818	8.882	77808	9.527	83453
10.0	7.857	68831	9.262	81133	9.973	87367
10.5	8.032	70360	9.572	83850	10.338	90557
11.0	8.156	71444	9.816	85989	10.627	93097
11.5	8.233	72121	9.997	87575	10.850	95049
12.0	8.269	72434	10.118	88630	11.012	96466
12.5	8.268	72425	10.180	89175	11.117	97386

CURVES P(V) and Pm(Vm) (Weibull's shape, k = 2)



DT870827 (1)

KRIEGSPIEL : NOWADAY EVALUATION OF "TROMELIN" PROJECT

1. REQUIREMENTS

Daily energy -- 50 kWh

Peak power -- 9 kVA

Voltage distorsion ---------------------------------- low

Powerful induction motor ---------------------------- no

Running time to be
given by the battery bank --------------------------- 5 days

2. DATA

2.1. WIND REGIME

Average wind velocity (10 m height above ground) ---- 6.5 m/s

WEIBULL's law shape factor ------------------------- 4

2.2 AUTONOMOUS WINDPOWERED ELECTRICITY GENERATING SYSTEM OVERALL EFFICIENCY

r(cea) --- 0,75

3. PROPOSED AEROWATT-INTERNATIONAL EQUIPMENT

- 1 windgenerator ---------------- UM100(Vms40)/10000/BAT-NC

- 1 tower ---------------------------------- SH100(Vms40)-180

Average wind velocity at hub height ---- 6.5 x 1.08 = 7.02 m/s

Theoretical yearly yield
for the above combination [E(aer)] -------------- 51 000 kWh

- 1 dual-conversion cabinet AW/CEA/1/10(50) with option B (output selftransformer rated 10 kVA)

Theoretical yearly available energy [E(res)] ----- 38 250 kWh

- 155 type TSE 750 cells (tubular positive plate lead acid cell, with C10 capacity of 750 Ah)

Usable capacity --------- 0.001 x 310 x 750 x 0.8 = 186 kWh
Extension of capacity due to low rate discharge ------- 50 %
Running time given by this
battery bank ---- (186 x 1.5):[50 :(0.95 x 0.95)] = 5.03 days

4. FOB PRICE (FRENCH HARBOUR)

- 549 000 FF or CAN 122 000 $ (currency CAN 1$ = 4.5 FF)

DT870827 (2)

KRIEGSPIEL : REEVALUATION OF THE "EUROPA" PROJECT

1. REQUIREMENTS

Daily energy -- 75 kWh

Peak power -- 15 kVA

Voltage distorsion ------------------------------------ low

Powerful induction motor ------------------------------ no

Running time to be
given by the battery bank ----------------------------- 2 days

2. DATA

2.1. WIND REGIME

Average wind velocity (10 m above ground) ----------- 4.3 m/s

WEIBULL's law factor -------------------------------- unknown
Assumed equal to ------------------------------------ 2

2.2. AUTONOMOUS WINDPOWERED ELECTRICITY GENERATING SYSTEM OVERALL EFFICIENCY

r(cea) -- 0.75

3. PROPOSED AEROWATT-INTERNATIONAL EQUIPMENT

- 2 windgenerators ------------------ UM100(Vms40)/10000/BAT-NC

- 2 towers -------------------------------- SH100(Vms40)-240

Average wind velocity at hub height ---- 4.3 x 1.14 = 4.9 m/s

Theoretical yearly yield
for the above two units [E(aer)] -------------- 49 000 kWh

- 1 dual-conversion cabinet AW/CEA/2/25(50) with option B (output selftransformer rated 25 kVA)

Theoretical yearly available energy [E(res)] --- 36 750 kWh

- 155 type TSE 750 cells (tubular positive plate lead acid cell, with C10 capacity of 750 Ah)
Usable capacity ----------- 0.001 x 310 x 750 x 0.8 = 186 kWh
Extension of capacity due to low rate discharge ------- 50 %
Running time given by this
battery bank ------ (186 x 1.5):[75:(0.95 x0.95)] = 3.36 days

4. FOB PRICE (FRENCH HARBOUR)

- 762 000 FF or CAN 169 350 $

- to be compared to the price of the delivered equipment (january 1986), with 3 UM70/86/5000/BAT-NC machines and 3 SH70-300towers, AW/CEA/3/25 dual-conversion unit 951 500 FF or CAN 211 450 $.

WIND TURBINE
FOUNDATIONS IN THE CANADIAN NORTH

Duncan Hume

My interest in wind turbine foundations in the Canadian North follows directly from my close involvement with the placing of a 60 kW wind turbine in Ft. Severn, the most Northerly town in Ontario.

The Ft. Severn contract involved the erection and operation of a high penetration wind turbine to run in parallel with three diesel prime movers that were to be the backbone of the isolated system. The contract was awarded by Ontario Hydro to Howden Group Canada in June 1985. The Howden HWP60 wind turbine is an upwind three-bladed propellor on a free-standing tower (see Appendix "A"). The schedule was prepared with the objective of doing most of the work during the short Summer and to keep the overall schedule as short as possible. We planned to build the 70 cubic metre foundation in August of 1985 and follow up with the wind turbine in July of 1986.

During the execution of the schedule, the difficulties came into focus. A foundation that would have been completed within a week or two, if it were to be placed into a Southern Ontario environment, took a couple of weeks to purchase and load onto a train. All the material, which included 300 bags of cement, 20 tons of rebar, a cement mixer, wood for the forms, etc. were marshalled at Moosonee before being loaded onto the barge for shipment to Ft. Severn. The barge was, at best, an annual event, and had not made the voyage in either of the two previous years. We began to understand the reasons for this erratic schedule as we waited for four weeks for the ice to clear off the Hudson's bay shoreline.

(This was August). The slow start was succeeded by an even more unnerving end. A short distance up the Severn River the barge went aground on one of the ever-changing sandbanks. For three days the tug pushed and pulled before getting the barge afloat again.

As far as Northern Canada goes, Ft. Severn has to be considered an excellent site for building a concrete foundation. There is good access, good aggregate and plenty of clean fresh water. Many Northern locations will not have these resources or the variety of heavy equipment that is available at Ft. Severn. It was obvious that commercial viability of wind turbines in remote areas would be significantly enhanced by a more economical foundation design than that used at Ft. Severn. An application to the Department of Energy, Mines and Resources requesting funding for an "Examination of Alternative Foundation Designs for Cost Reduction of Remote Wind/Diesel Systems" was successful, and a study of the options was commenced.

During the preliminary stages we elected to look at the general variety of soil types that were likely to be encountered within the Canadian North and then to identify suitable options for the foundations in each soil type. It was quickly determined that there are a great variety of soil types and that these could be in a wide variety of conditions, i.e. wet or dry, premafrost or semi-permafrost, etc. We concluded that it would be more beneficial to identify alternative foundation types and then to determine at what locations their application would be suitable.

A selection of the foundation designs that were developed is shown in Appendix "B". Attached Table 1 illustrates the applicability of the designs to the variety of soil conditions that might be encountered. Table 2 shows some cost estimates that were prepared to allow an evaluation of the suitability of the various options to specific sites.

My thanks to Andres Torke of Morrison Hershfield who was responsible for the foundation design of the wind turbine presently at Ft. Severn and who also took the lead role in the "Examination of Alternatives" project. A full copy of the report can be obtained from myself or by contacting EMR (file No. 51SZ 23216-6-6165).

TABLE I

SOIL/FOUNDATION TYPES

Foundation Type Soil Type	Shallow Concrete Footing	Steel Grillage	Timber Grillage	Piles (frozen-in)	Screw Anchors	Rock Anchors
Weak Cohesive	F1	F4	F5		F6 F7	
Stiff Cohesive	F2 F3	F4	F5		F6 F7	
Granular	F2 F3	F4	F5		F6 F7	
Weathered Rock	F3	Possible	Possible			F8 F9
Sound Rock						F8 F9
Permafrost	Possible		Possible	F6 F7		
Muskeg	Possible with soil replacement	Possible with soil replacement	Possible with soil replacement	F6 or F7 with permafrost below	F6 or F7 with unfrozen firm soil below	

Table indicates Drawing Nos. of applicable typical foundation designs. The designs have to be modified where the soil conditions assumed for the typical designs are not met.

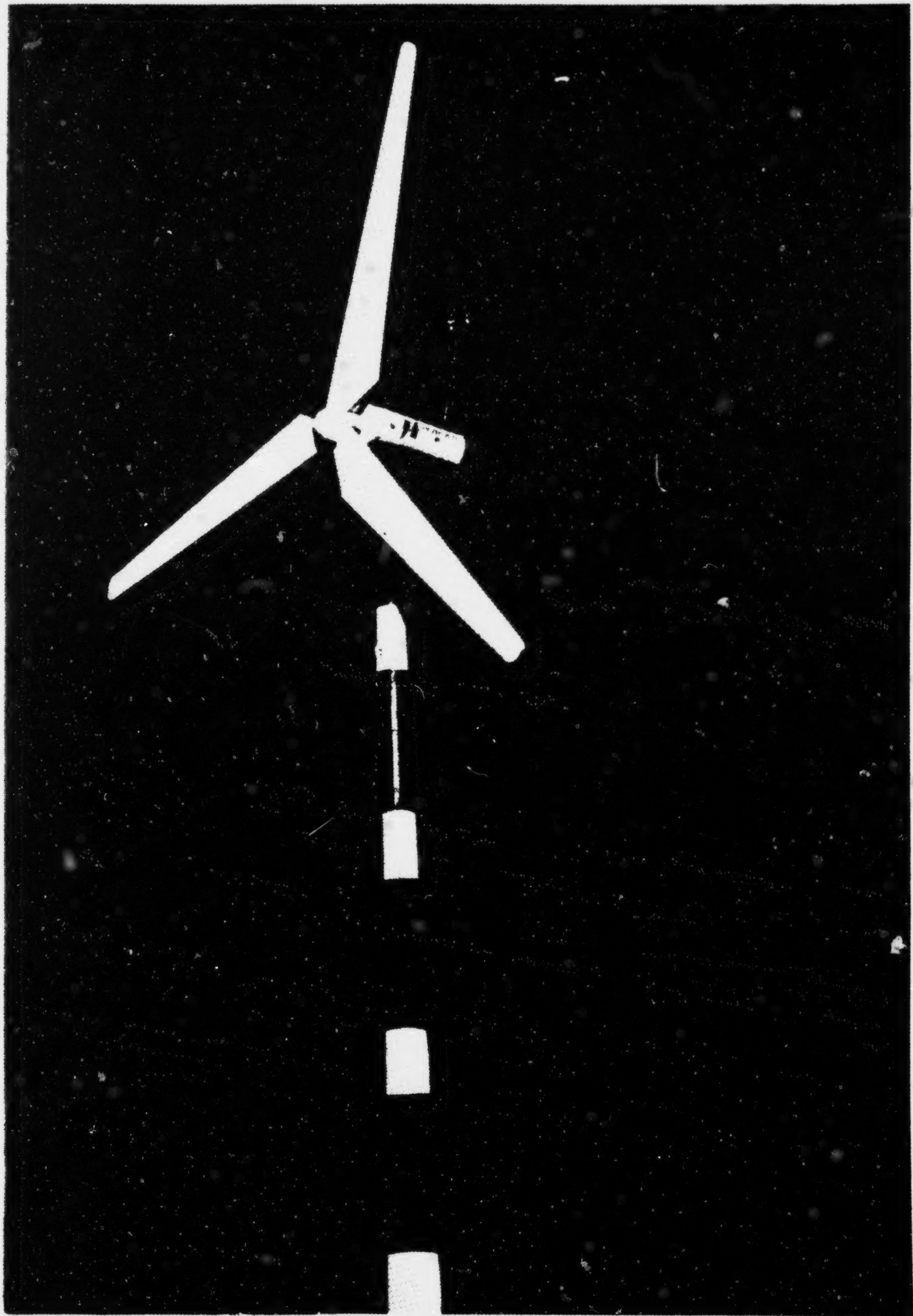
TABLE 2

Prelim Cost Estimates - for an accessible South Ontario Site:

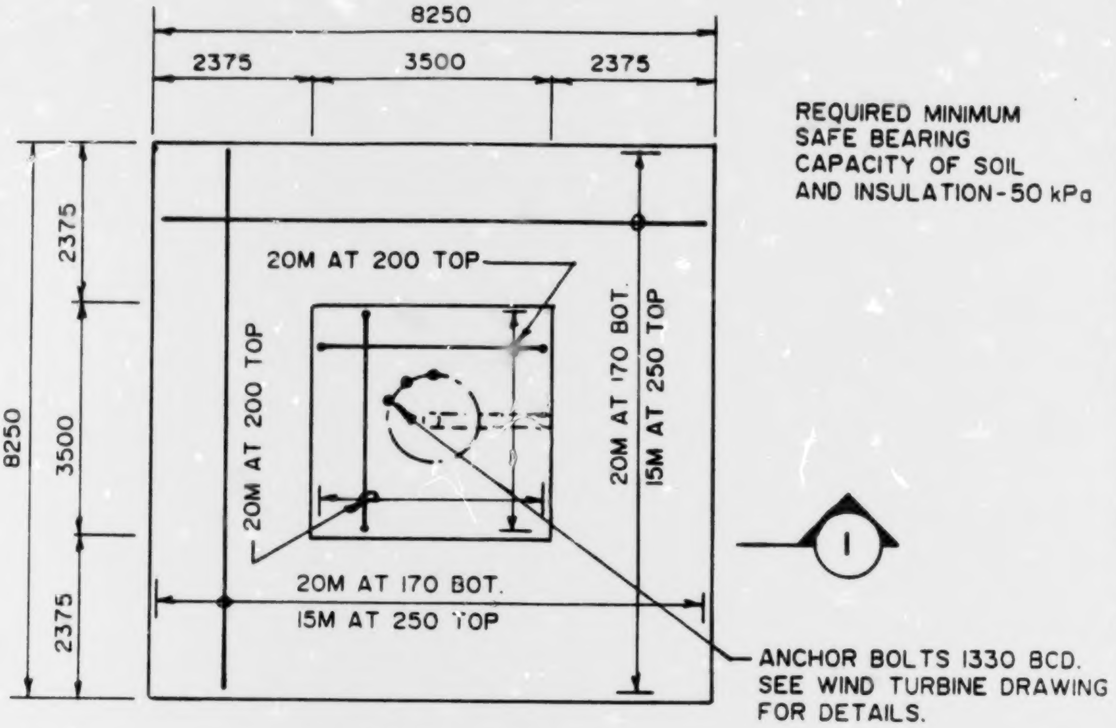
	Drawing *	Estimate $
Shallow conc footing 50 kPa soil	F1	25,000
Shallow conc footing 100 kPa soil	F2	23,000
Shallow conc footing 200 kPa soil	F3	20,000
Steel grillage foundation 100 kPa soil	F4	30,000
Timber grillage foundation 100 kPa soil	F5	36,000
Pile/screw anchor foundation with concrete cap (10 m piles)	F6	27,000
Pile/screw anchor foundation with steel frame cap (10 m piles)	F7	29,000
Concrete footing on sound rock	F8	18,000
Steel grillage foundation on sound rock	F9	23,000

* Ref - Report No 18706011

APPENDIX "A"

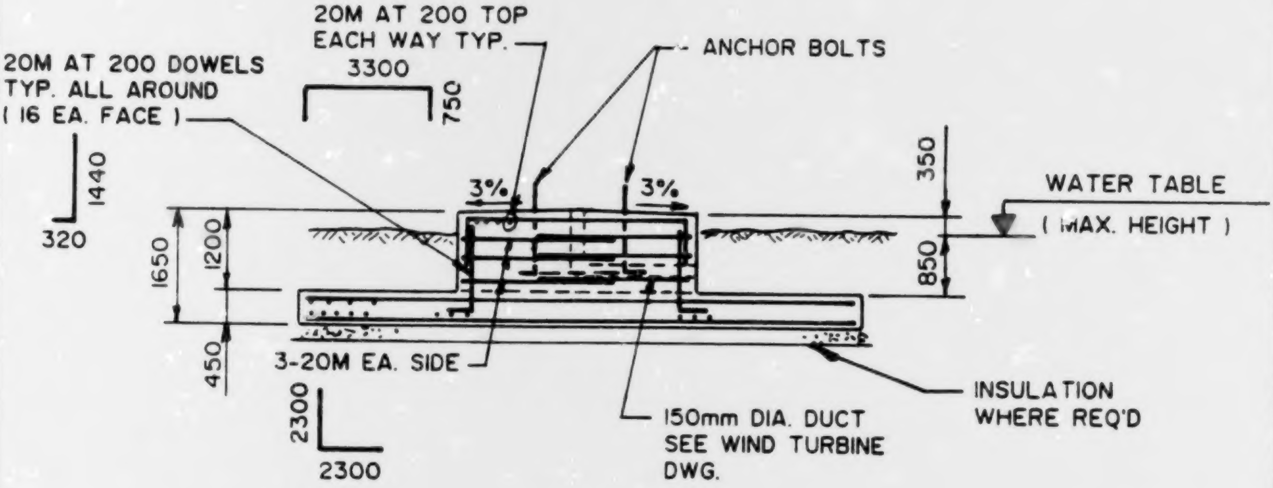


APPENDIX "B"
Page 1


8250
2375
3500
2375
2375
3500
2375
8250
20M AT 200 TOP
20M AT 200 TOP
20M AT 170 BOT.
15M AT 250 TOP
20M AT 170 BOT.
15M AT 250 TOP
1
ANCHOR BOLTS 1330 BCD.
SEE WIND TURBINE DRAWING
FOR DETAILS.

REQUIRED MINIMUM
SAFE BEARING
CAPACITY OF SOIL
AND INSULATION - 50 kPa

FOUNDATION PLAN
1 : 100

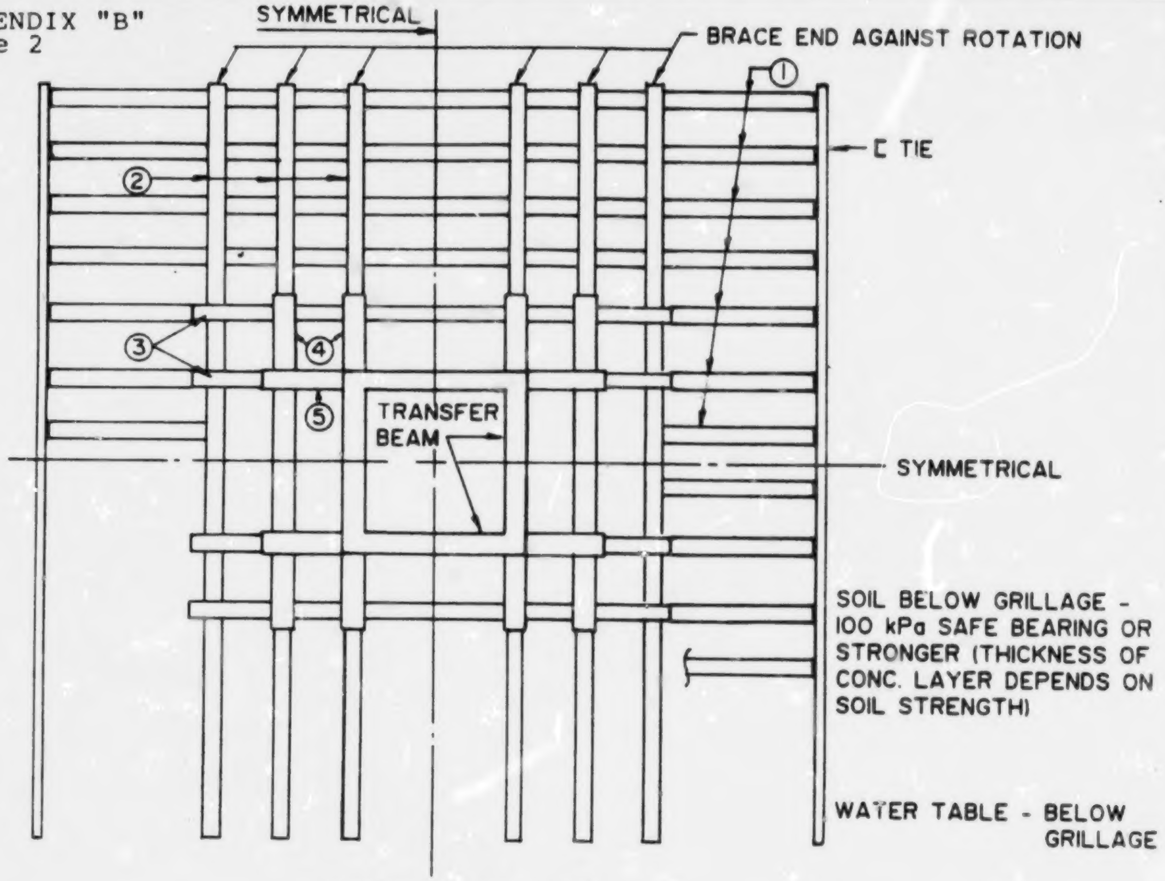

20M AT 200 TOP
EACH WAY TYP.
ANCHOR BOLTS
20M AT 200 DOWELS
TYP. ALL AROUND
(16 EA. FACE)
3300
750
1440
320
3%
3%
350
WATER TABLE
(MAX. HEIGHT)
850
1650
1200
450
3-20M EA. SIDE
2300
2300
150mm DIA. DUCT
SEE WIND TURBINE
DWG.
INSULATION
WHERE REQ'D

SECTION ①
1 : 100

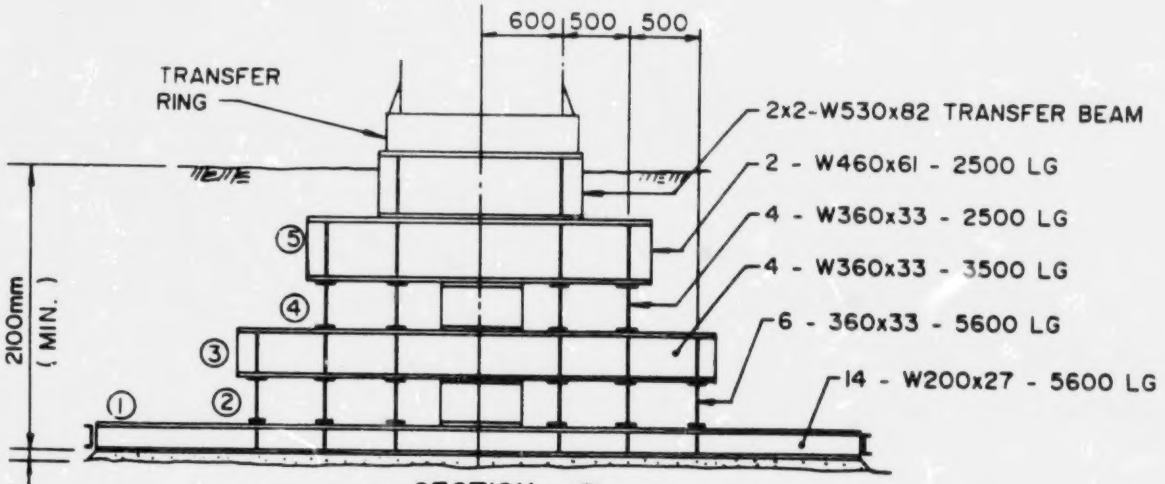
Morrison Hershfield Limited
Consulting Engineers

SHALLOW CONCRETE FOOTING
50 kPa SOIL

DESIGNED: M.A.M.
DRAWN: J.C.
PROJ. ENG.: A.T.
APPROVED:
DRAWING NO.: 187-0601-F1
SCALE: 1 : 100
DATE: APRIL. 1987


SYMMETRICAL
BRACE END AGAINST ROTATION
①
②
℄ TIE
③
④
⑤
TRANSFER BEAM
SYMMETRICAL
SOIL BELOW GRILLAGE - 100 kPa SAFE BEARING OR STRONGER (THICKNESS OF CONC. LAYER DEPENDS ON SOIL STRENGTH)
WATER TABLE - BELOW GRILLAGE

FOUNDATION PLAN


600
500
500
TRANSFER RING
2x2-W530x82 TRANSFER BEAM
2 - W460x61 - 2500 LG
4 - W360x33 - 2500 LG
4 - W360x33 - 3500 LG
6 - 360x33 - 5600 LG
14 - W200x27 - 5600 LG
2100mm (MIN.)
⑤
④
③
②
①

SECTION ①

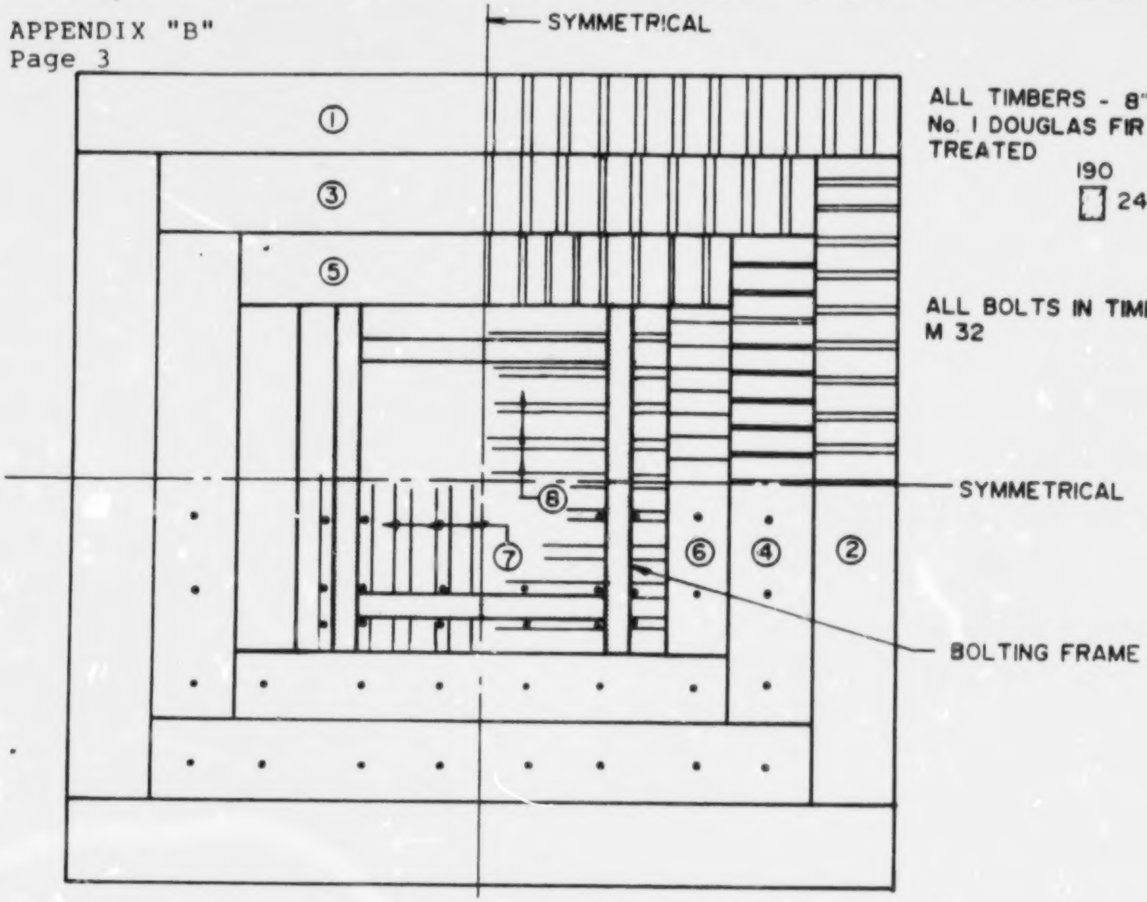
CONC. LAYER BELOW BEAMS : -
MIN. THICKNESS -
- 65 FOR 100 kPa SOIL
- 40 FOR 200 kPa SOIL (NOMINAL)

Morrison Hershfield Limited
Consulting Engineers

STEEL GRILLAGE FOUNDATION
ON 100 kPa SOIL

DESIGNED: M.A.M.
DRAWN: S.L.
PROJ. ENG.: A.T.
APPROVED:
DRAWING NO.:
187-0601-F4

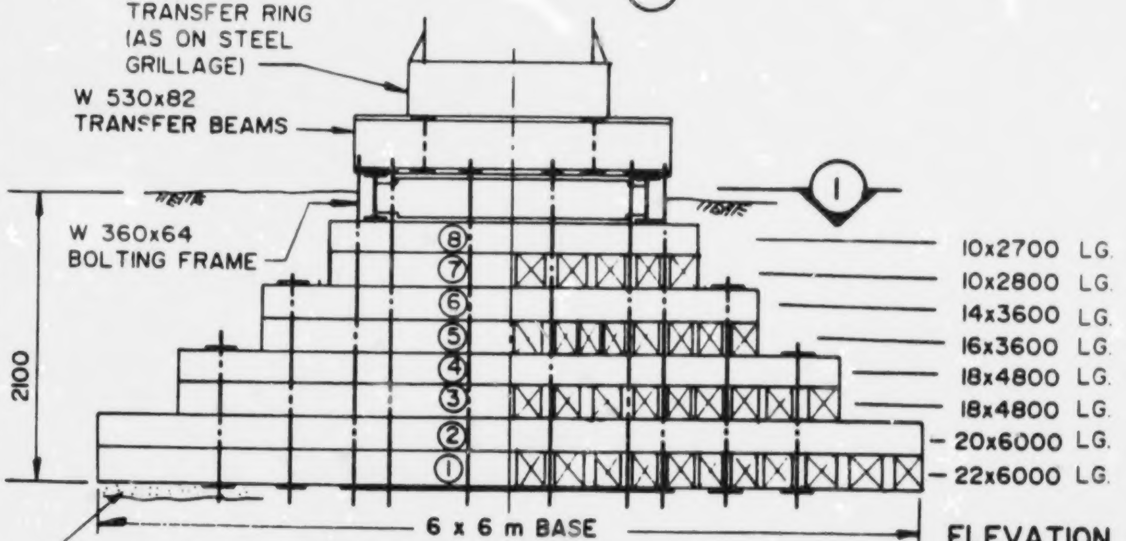
SCALE: 1:50
DATE: APRIL, 1987


SYMMETRICAL
①
③
⑤
⑧
⑦
⑥
④
②
SYMMETRICAL
BOLTING FRAME

ALL TIMBERS - 8" x 10"
No. 1 DOUGLAS FIR
TREATED
190
240

ALL BOLTS IN TIMBER
M 32

FOUNDATION PLAN ①


TRANSFER RING
(AS ON STEEL
GRILLAGE)
W 530x82
TRANSFER BEAMS
W 360x64
BOLTING FRAME
2100
①
⑧
⑦
⑥
⑤
④
③
②
①
10x2700 LG.
10x2800 LG.
14x3600 LG.
16x3600 LG.
18x4800 LG.
18x4800 LG.
20x6000 LG.
22x6000 LG.
6 x 6 m BASE

ELEVATION

40 CONCRETE LAYER
OR SMOOTH COMPACTED
SOIL.

SOIL - 100 kPa SAFE BEARING.

WATER TABLE BELOW GRILLAGE

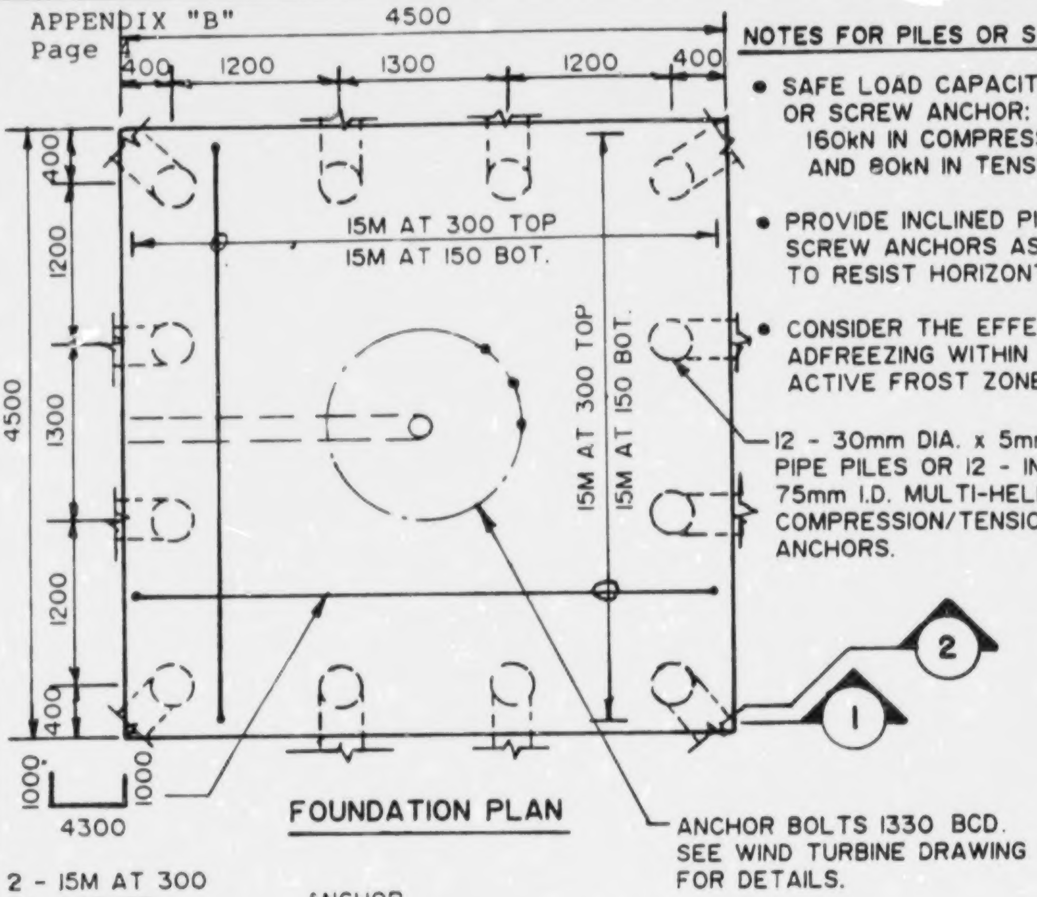
Morrison Hershfield Limited
Consulting Engineers

**TIMBER GRILLAGE FOUNDATION
ON 100 kPa SOIL**

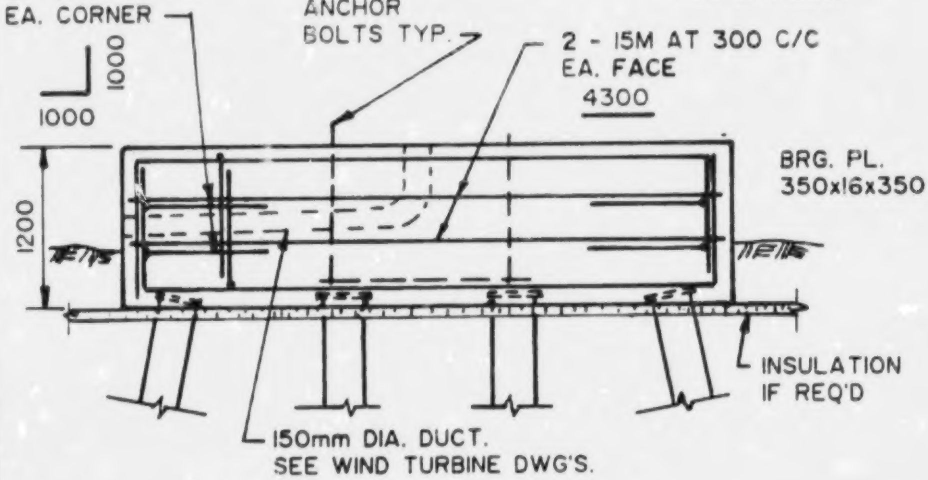
DESIGNED: A.T.
DRAWN: S.L.
PROJ. ENG.: A.T.
APPROVED:
DRAWING NO.: 187-0601-F5
SCALE: 1:50
DATE: APRIL, 1987

NOTES FOR PILES OR SCREW ANCHORS

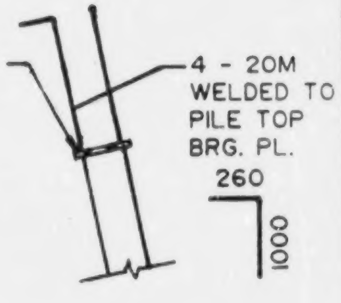
- SAFE LOAD CAPACITY OF ONE PILE OR SCREW ANCHOR:
  160kN IN COMPRESSION
  AND 80kN IN TENSION.
- PROVIDE INCLINED PILES OR SCREW ANCHORS AS REQ'D. TO RESIST HORIZONTAL LOADS.
- CONSIDER THE EFFECT OF ADFREEZING WITHIN THE ACTIVE FROST ZONE.


4500
400
1200
1300
1200
400
15M AT 300 TOP
15M AT 150 BOT.
15M AT 300 TOP
15M AT 150 BOT.
4500
400
1200
1300
1200
400
1000
1000
4300
12 - 30mm DIA. x 5mm THICK PIPE PILES OR 12 - INCLINED HS-11 75mm I.D. MULTI-HELIX COMPRESSION/TENSION SCREW ANCHORS.
2
1
ANCHOR BOLTS 1330 BCD. SEE WIND TURBINE DRAWING FOR DETAILS.

FOUNDATION PLAN


2 - 15M AT 300 EA. CORNER
1000
1000
ANCHOR BOLTS TYP.
2 - 15M AT 300 C/C EA. FACE
4300
1200
INSULATION IF REQ'D
150mm DIA. DUCT. SEE WIND TURBINE DWG'S.

SECTION ①


BRG. PL. 350x16x350
4 - 20M WELDED TO PILE TOP BRG. PL.
260
1000

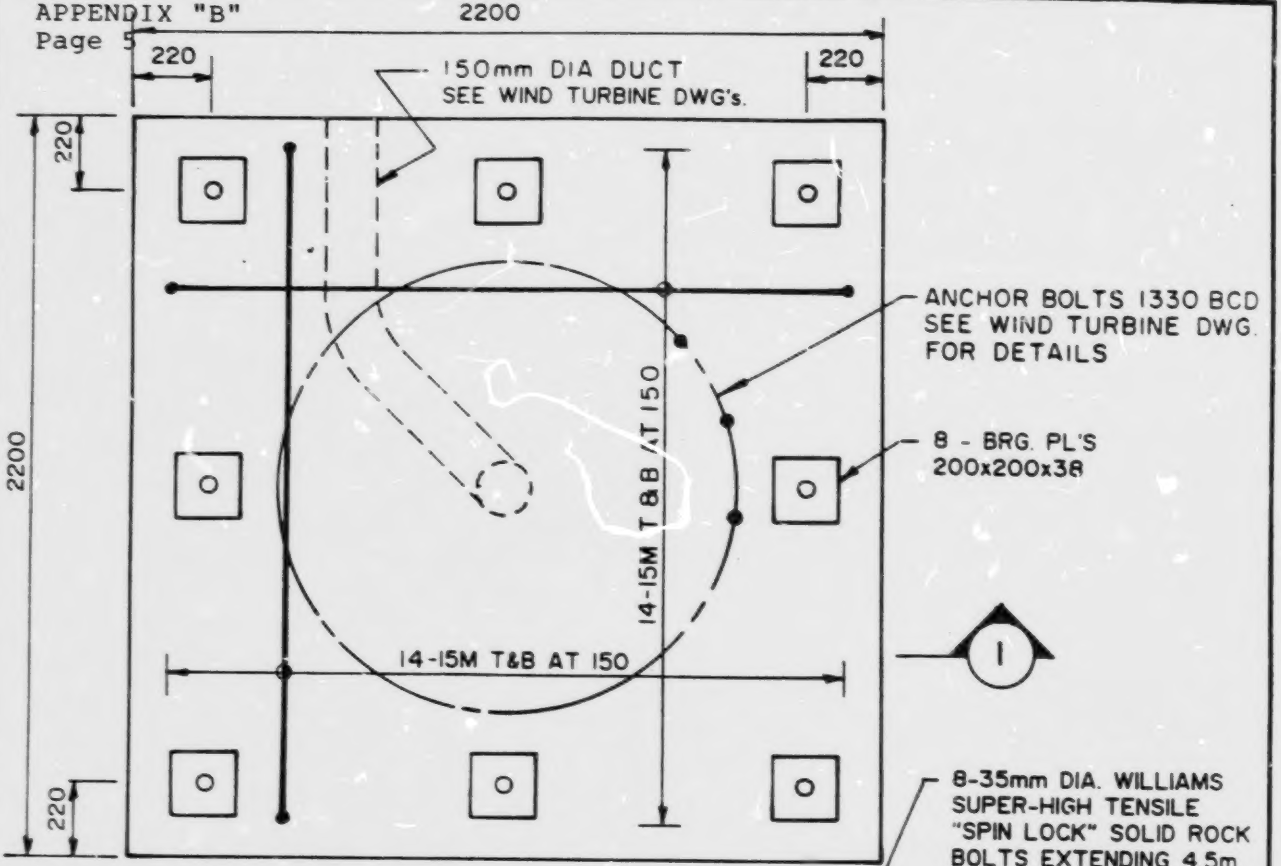
SECTION ②

Morrison Hershfield Limited
Consulting Engineers

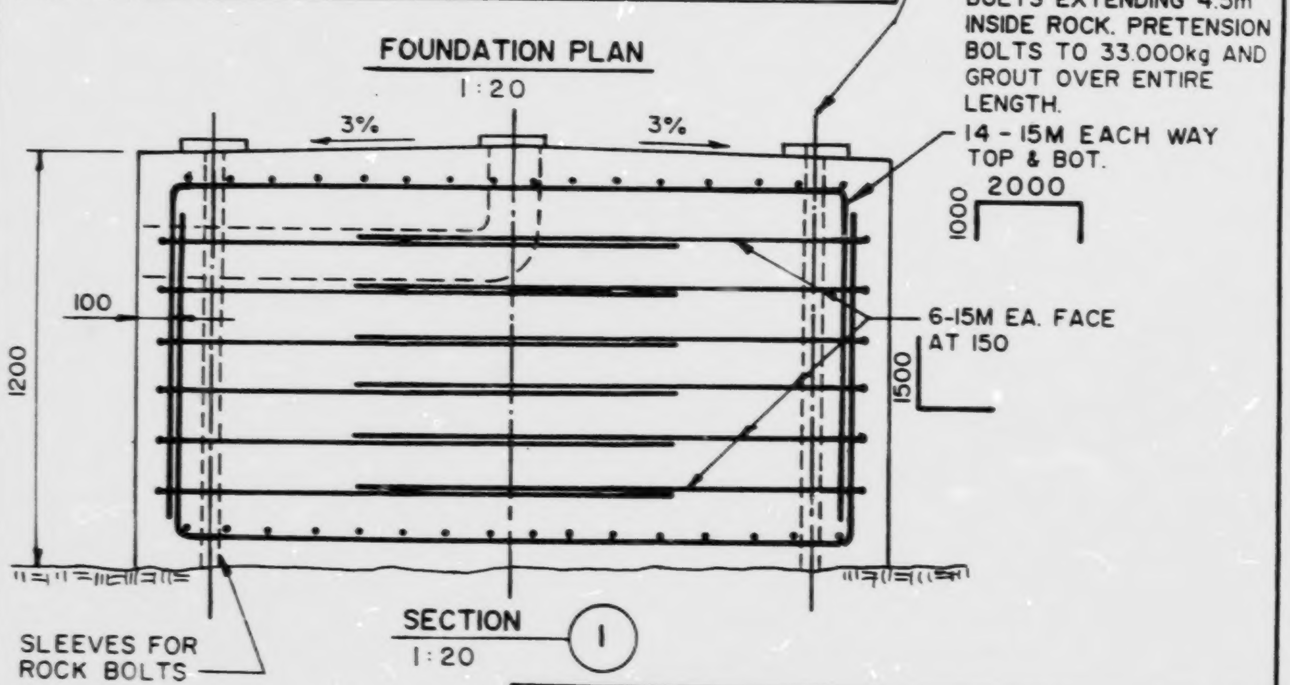
DESIGNED:	M.A.M.
DRAWN:	J.C.
PROJ. ENG.:	A.T.
APPROVED:	
DRAWING NO.:	187-0601-F6

PILE/SCREW ANCHOR FOUNDATION
WITH CONCRETE CAP

SCALE: 1 : 50
DATE: APRIL. 1987.


2200
220
220
150mm DIA DUCT
SEE WIND TURBINE DWG's.
220
2200
220
ANCHOR BOLTS 1330 BCD
SEE WIND TURBINE DWG.
FOR DETAILS
14-15M T&B AT 150
8 - BRG. PL'S
200x200x38
14-15M T&B AT 150
1

FOUNDATION PLAN
1:20


8-35mm DIA. WILLIAMS
SUPER-HIGH TENSILE
"SPIN LOCK" SOLID ROCK
BOLTS EXTENDING 4.5m
INSIDE ROCK. PRETENSION
BOLTS TO 33.000kg AND
GROUT OVER ENTIRE
LENGTH.
3%
3%
14 - 15M EACH WAY
TOP & BOT.
2000
1000
100
6-15M EA. FACE
AT 150
1200
1500
SLEEVES FOR
ROCK BOLTS

SECTION 1
1:20

REQUIRED MINIMUM SAFE BEARING CAPACITY - 1000 kPa

Morrison Hershfield Limited
Consulting Engineers

CONCRETE FOOTING
ON SOUND ROCK

DESIGNED: M.A.M.
DRAWN: S.L.
PROJ. ENG.: A.T.
APPROVED:
DRAWING NO.: 187-0601-F8

SCALE: 1:20
DATE: APRIL, 1987

MONITORING RESULTS FROM FOUR UTILITY-CONNECTED WIND GENERATORS

John Martin
Marketing Services
TransAlta Utilities Corporation

SUMMARY

Since 1984, TransAlta Utilities has been monitoring selected wind generators of the seven currently interconnected with its electric system. At the end of 1986, the second full year of data collection, two 5 kW wind generators, a 25 kW wind generator, and a 40 kW wind generator, all in southern Alberta, were being monitored.

In 1986, the monitored wind generators produced 128,298 kWh of electricity (124,898 kWh in 1985). They were actually generating electricity at some level for 37.5 per cent of the time in 1986 (45.3 per cent of the time in 1985). Average capacity factor for the wind generators was 26.1 per cent in 1986 (28.6 per cent in 1985). During hours of peak electric system demand, the wind generators were operating on average at 24 per cent of their rated capacities in 1986 (10 per cent in 1985).

TransAlta will continue to monitor these four wind generators until the end of the five year monitoring program, on December 31, 1989.

WIND GENERATORS INTERCONNECTED WITH TRANSALTA

In February 1980, the first wind-powered electric generator to be interconnected with TransAlta Utilities' electric system was installed in Strathmore, Alberta. That unit has since been dismantled, but several other wind generators have been interconnected in southern Alberta, both directly with TransAlta and with TransAlta's wholesale customers (that is, cities and towns).

As of September 1987, seven privately-owned wind generators are directly interconnected with TransAlta's electric system, with a total installed capacity of 177 kW. The owner of a 12 kW wind generator has also applied for its interconnection.

Three wind generator sites with a total installed capacity of 127 kW have interconnections with TransAlta wholesale customers. As well, the owner of a 65 kW wind generator has applied for interconnection with a TransAlta wholesale customer.

In total, including both direct and indirect customers and installed and applied for wind generators, projected wind generator capacity in TransAlta's utility service area in southern Alberta is currently 381 kW.

TRANSALTA'S MONITORING PROGRAM

Of the seven wind generators directly interconnected with TransAlta, four are being extensively monitored in a five-year program. The four units total 75 kW of capacity, and all are three-bladed, horizontal-axis, downwind units manufactured in the United States. The four units are:

- a 5 kW unit installed just outside Cardston, Alberta, in December 1983, providing electricity to a residence;
- a 40 kW unit installed just outside Pincher Creek, Alberta, also in December 1983, providing electricity to a residence, farm, and fertilizer plant;
- another 5 kW unit also installed just outside Pincher Creek, Alberta, in April 1984, providing electricity to a residence and farm; and
- a 25 kW unit installed outside Walsh, which is near Medicine Hat, Alberta, in March 1986, providing electricity to a ranch.

These four wind generators are being monitored as a result of a 1984 decision (Decision D 84-12) by the Alberta Energy Resources Conservation Board (ERCB). The decision came from a hearing on an application by the owner of the 40 kW wind generator, asking the ERCB to address matters relating to the allocation of costs and other terms and conditions associated with the interconnection of his wind generator to TransAlta's electricity distribution system. As part of its decision, the ERCB requested TransAlta, with the cooperation of the wind generator owners, collect information on the operation of selected wind generators and on their interaction with TransAlta's electric system and with the Alberta Interconnected System (AIS). TransAlta is to monitor and collect operating information on the specified wind generators for the duration of the trial period set by the ERCB, ending on December 31, 1989.

1986 was TransAlta's second complete year of data collection. For 1986, "total" refers to three wind generators, with a combined generating capacity of 50 kW, from January to September inclusive, and four wind generators, with a combined generating capacity of 75 kW, from October to December inclusive. For 1985, "total" refers to three wind generators only, with a combined generating capacity of 50 kW.

MONITORING RESULTS

Energy Production

The most basic monitoring result is the amount of energy produced. During 1986, the four Small Power Producer (SPP) wind generators monitored by TransAlta generated a total of 128,298 kWh of electric energy, shown in Figure 1 on the next page. In general, electric energy generated by a wind generator was primarily used to meet the SPP's needs at the time of generation. However, when energy generated by a wind generator exceeded the SPP's immediate needs, the excess energy was "banked" in TransAlta's electric system. During times of low or no winds, this banked energy could be withdrawn from the electric system to meet the SPP's needs.

Through this "quarterly net energy banking", one of the monitored SPPs generated enough energy to fully meet his own energy use. The other three SPPs purchased some energy from TransAlta to supplement their wind generator's

Figure 1: Wind Generators Produced 128,298 kWh Of Electricity in 1986

Four Wind Generators: 75 kW Generating Capacity

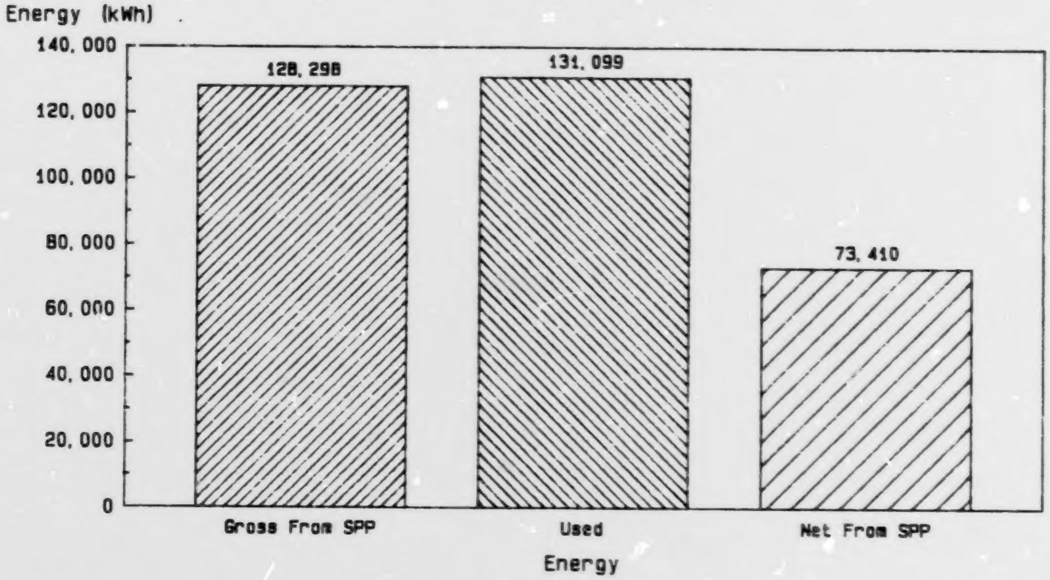
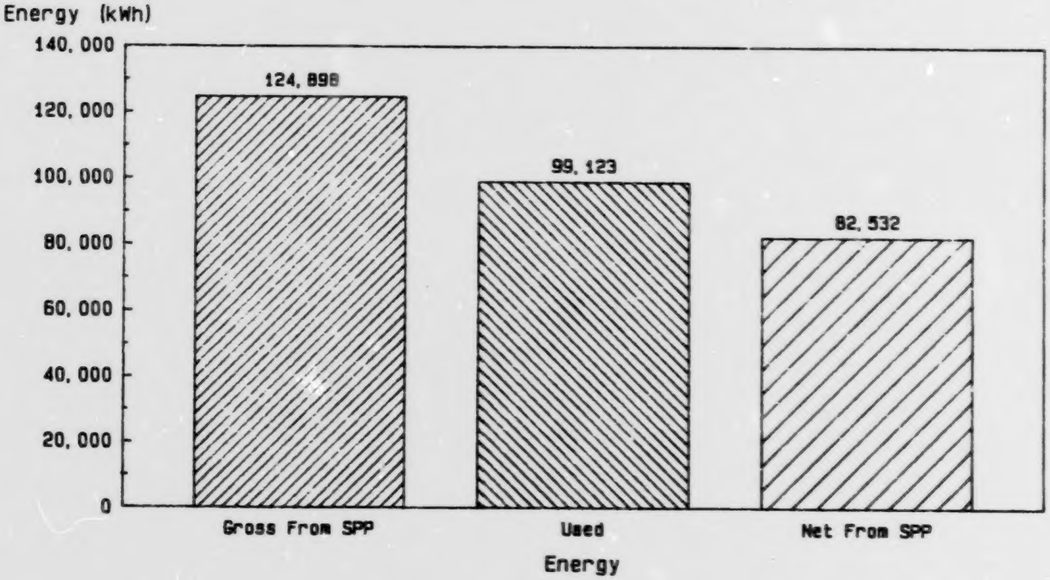


Figure 2: Wind Generators Produced 124,898 kWh Of Electricity in 1985

Three Wind Generators: 50 kW Generating Capacity



output. The total amount of energy used by all SPPs in 1986, whether supplied by the wind generators or purchased from TransAlta, was 131,099 kWh.

Of the 128,298 kWh of "gross" generation, 73,410 kWh were in excess of immediate needs. This "net" generation was banked in TransAlta's electric system for later use or sale to TransAlta.

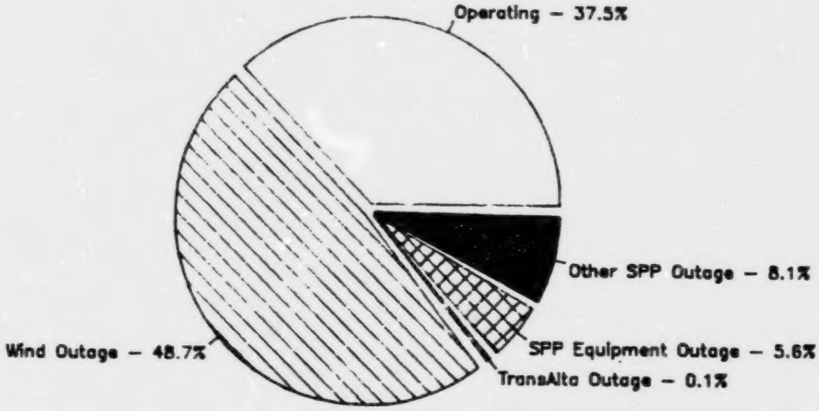
For comparison, Figure 2 on the previous page shows that the three SPPs monitored during 1985 produced a total of 124,898 kWh of gross generation. At the same time, the total amount of energy used by all three SPPs in 1985, whether supplied by the wind generators or purchased from TransAlta, was 99,123 kWh.

Of the 124,898 kWh of gross generation in 1985, net generation (in excess of immediate needs) of 82,532 kWh was banked in TransAlta's electric system for later use or sale to TransAlta.

Availability

A wind generator facility that has been fully installed and monitored, and for which monitoring data is available, is at any time considered to be in one and only one of the following states: service, wind outage, TransAlta outage, SPP equipment outage, or other SPP outage. In 1986, the four monitored wind generators, on average, were in service for 37.5 per cent of the time, shown in Figure 3 below. The wind generators were out of service due to resource outages for 48.7 per cent of the time, due to TransAlta outages for 0.1 per cent of the time, due to SPP equipment outages for 5.6 per

Figure 3: Wind Generators Operated 37.5% Of the Time on Average in 1986
Four Wind Generators: 75 kW Generating Capacity



Percentage of Time

cent of the time, and due to other SPP outages for 8.1 per cent of the time. From these states, availabilities, shown in Figure 4 on the next page, can be calculated to compare time spent in each state.

First of all, the percentage of monitored time in which wind conditions were suitable for wind generator operation is resource availability. During 1986, average resource availability was 51.3 per cent.

Second, the percentage of that time (with suitable wind conditions) in which TransAlta equipment was also suitable for wind generator operation is TransAlta availability. Average TransAlta equipment availability at the wind generator sites was 99.8 per cent in 1986.

Third, the percentage of that time (with suitable wind and TransAlta equipment conditions) in which SPP equipment allowed wind generator operation is SPP equipment availability. During 1986, average SPP equipment availability was 89.1 per cent.

Finally, the percentage of that time (with suitable wind, TransAlta equipment, and SPP equipment conditions) in which other conditions affecting SPP operation were suitable for generation is other SPP availability. Average availability of other SPP conditions affecting generation was 82.3 per cent in 1986.

These four availabilities combine to give an overall availability factor of 37.5 per cent. This is the percentage of monitored time in which all conditions were suitable for wind generation operation - that is, the percentage of time that the wind generators actually operated.

For comparison, Figure 5 on the next page shows that the three SPPs monitored during 1985 had an average wind availability of 54.0 per cent, an average TransAlta availability of 99.9 per cent, an average SPP equipment availability of 92.6 per cent, and an average other SPP availability of 90.6 per cent. Average overall availability in 1985 was 45.3 per cent.

Capacity Factor

Although the four monitored wind generators were operating for 37.5 per cent of the time in 1986, they were not necessarily operating at their rated capacity for that time. In fact, based on gross generation, the wind generators operated at an average capacity factor of 26.1 per cent during 1986, shown in Figure 6 on the page after next. Capacity factor is the ratio of actual energy generated in a period to the potential energy that could have been generated had the wind generator operated at its rated capacity over the entire period.

For comparison, Figure 7 on the page after next shows that in 1985 the three monitored wind generators operated at an average capacity factor of 28.6 per cent, based on gross generation.

Figure 4: Wind Generators Operated 37.5% Of the Time on Average in 1986

Four Wind Generators: 75 kW Generating Capacity

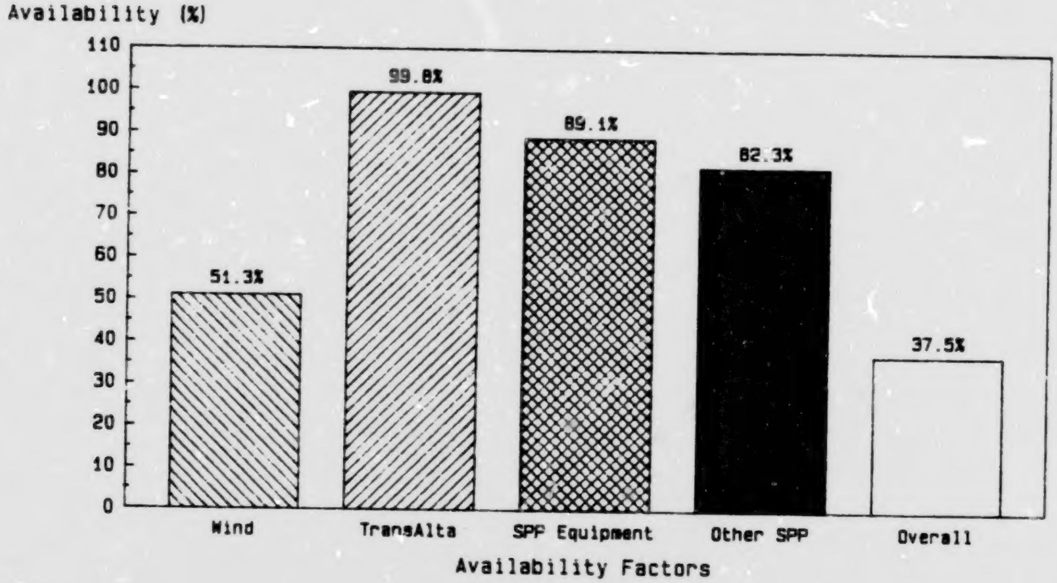


Figure 5: Wind Generators Operated 45.3% Of the Time on Average in 1985

Three Wind Generators: 50 kW Generating Capacity

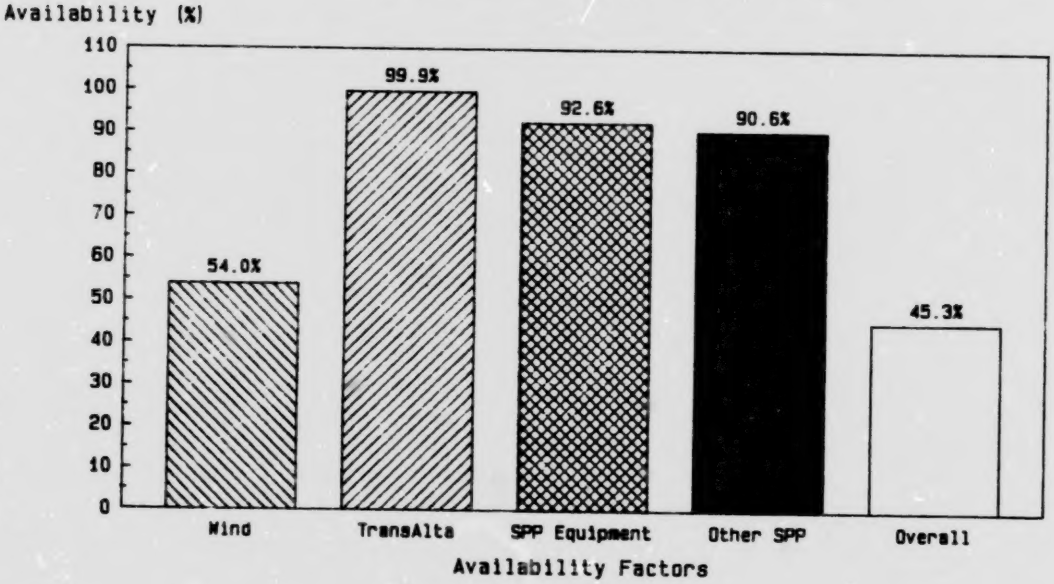


Figure 6: Wind Generators Produced 26.1%
Of Their Rated Output on Average in 1986
Four Wind Generators: 75 kW Generating Capacity

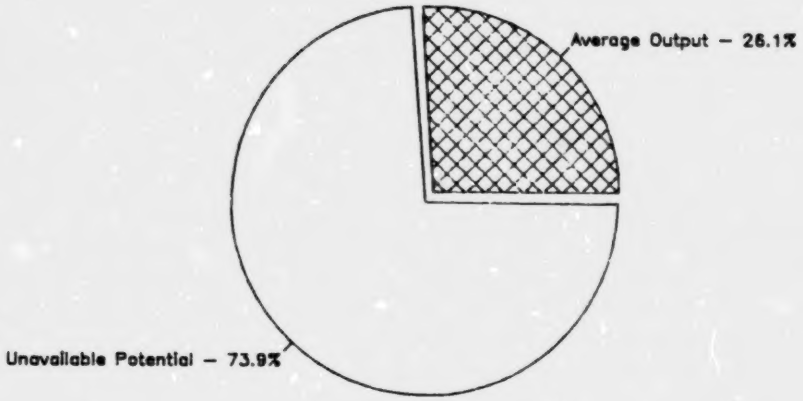
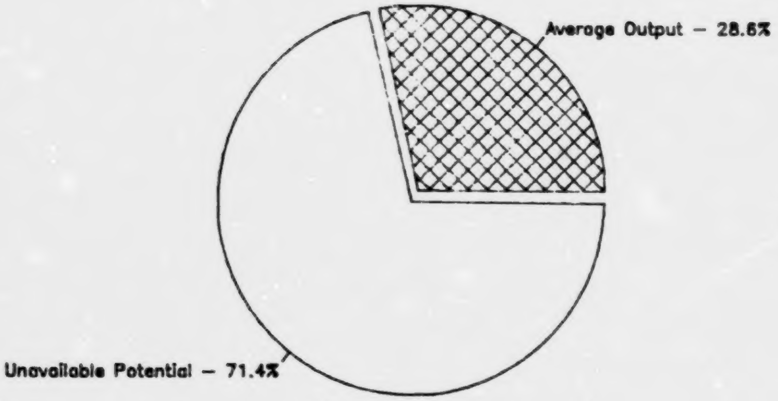


Figure 7: Wind Genertors Produced 28.6%
Of Their Rated Output on Average in 1985
Three Wind Generators: 50 kW Generating Capacity



Generation Coincident With Electric System Peak Demands

Average capacity factor over the year is an important measure of performance of a wind generator. However, from a utility viewpoint generation during times of peak demand may be even more important.

The amount of generating capacity installed on a utility system is based on the projected peak demands occurring on that system. In 1986, the peak demand on the Alberta Interconnected System (AIS) was 4,900.6 megawatts (MW), occurring from 5:01 PM to 6:00 PM on December 8. In total during 1986, 26 hours were within five per cent of this annual peak - that is, 26 hours occurred with demand greater than 4,655.6 MW. Figure 8 on the next page shows those 26 hours. During those 26 hours of highest AIS demand in 1986, the four monitored wind generators, on average, were generating 24 per cent of their rated output.

For comparison, AIS peak demand in 1985 was 4,926.4 MW, occurring from 5:01 PM to 6:00 PM on November 26. (The 1986 AIS peak demand was lower than the 1985 AIS peak demand because the 1986 winter was much milder than the 1985 one.) Figure 9 on the next page shows the 20 hours that were within five per cent of this annual peak - that is, the 20 hours that occurred with demand greater than 4,680.1 MW. During those 20 hours of highest AIS demand in 1986, the three monitored wind generators, on average, were generating 10 per cent of their rated output.

CONCLUSION

The monitoring of utility-connected wind generators being carried out by TransAlta Utilities is providing valuable information on the interaction of wind generators with a utility system. However, conclusions should not be drawn from the two years of monitoring data collected so far in what will be a five-year program. Several years of data is essential before long-term conclusions can be drawn.

More detailed information is available, both on TransAlta's wind generator monitoring program and on the results of the monitoring. For copies of the 1986 Report Summary RE 102 and/or the 1985 Report Summary RE 101A, please contact:

Marketing Services, PBS-7
TransAlta Utilities Corporation
110 - 12th Avenue SW
Box 1900
Calgary, Alberta
T2P 2M1

The 1987 Report Summary RE 103 will be prepared by TransAlta Utilities before the end of March 1988.

Figure 8: During Hours of Peak Demand, Wind Generators Averaged 24% of Their Rated Output in 1986

Four Wind Generators: 75 kW Generating Capacity

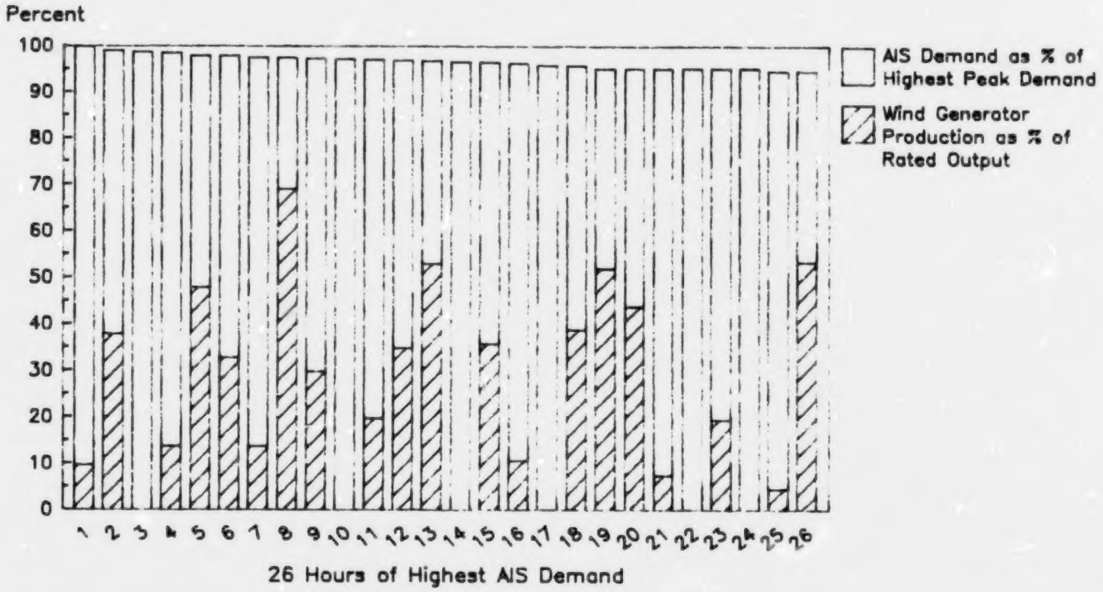
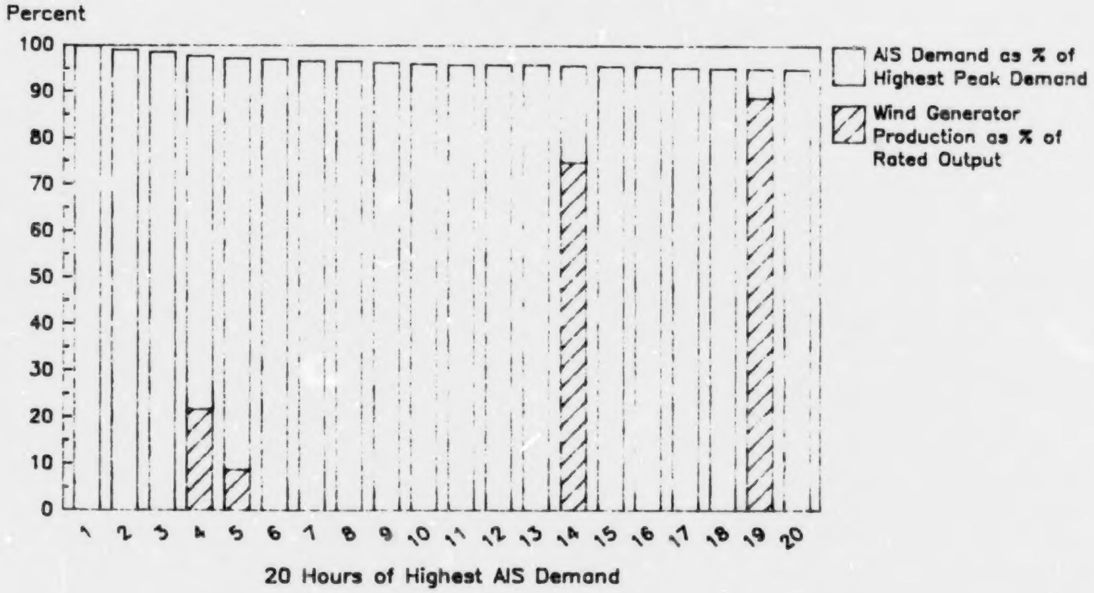


Figure 9: During Hours of Peak Demand, Wind Generators Averaged 10% of Their Rated Output in 1985

Three Wind Generators: 50 kW Generating Capacity



TECHNOLOGY DEVELOPMENTS I

HIGH ENERGY DARRIEUS ROTOR

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HIGH ENERGY DARRIEUS ROTOR

D.J. Malcolm
Indal Technologies Inc.

1. INTRODUCTION

The economics of wind turbine manufacture and operation is affected by many factors. Among the more important factors is the cost of the transmission and the electrical generators which is commonly at least 60% of the total cost (1). These components must be sized to match the maximum power that will be captured by the rotor although this maximum power may be reached on relatively few occasions if sufficiently high windspeeds are infrequent (as is often the case). It can, therefore, be of economic advantage to limit the peak power generated by the rotor in order to reduce the governing design requirements.

In recognition of this situation, there has been considerable research recently in the United States into developing a family of airfoils especially suited to vertical axis wind turbines (2,3). These airfoils exhibit stall at lower angles of attack than do the NACA00 series used until now, and thereby limit the aerodynamic lift and rotor power.

The performance of these special airfoils have been studied in wind tunnel tests (4) and have been confirmed by Sandia National Laboratories where they were installed as the central sections of their 17m test rotor (5). Not only was the peak power output lowered but the value of the lead-lag cyclic stresses was also reduced. In addition, the wind tunnel tests have indicated that surface roughness (from insect accumulation, for example) will affect the performance of tailored airfoils no more than it affects the conventional NACA00 airfoils (3). The properties of these "tailored" airfoils have also been utilized by Sandia National Laboratories in the design of their 34m large test bed machine (4,5). The rationale behind that machine is that the surest way to increase total energy capture is by increasing the swept area. This can be accomplished without a corresponding increase in rated power by incorporating tailored airfoils in the mid-rotor region.

This paper presents the findings of a study carried out by Indal Technologies Inc. on behalf of Energy, Mines and Resources, Ottawa. The objective of the study was to investigate the technical and economic feasibility of building a rotor which utilized the tailored airfoils. The following guidelines were used.

(1) Two new rotors were examined: one had a constant blade chord of .763 m with a tailored airfoil while the other combined the tailored airfoil with a step-tapered chord resulting in a greater chord dimension near the upper and lower blade roots.

(2) The rated power of both the rotors was approximately 520 kW (electrical) at sea level. This is the same as the present Indal Technologies Inc. 6400 VAWT.

(3) The remaining design details were, where possible, based upon those of the existing Indal Technologies Inc. 6400 VAWT.

(4) The output of each machine was calculated for wind regimes corresponding to North Cape on PEI and for a site on the Magdalen Islands.

(5) Costs were estimated on the basis of a group of twenty machines.

2. CONFIGURATIONS SELECTED

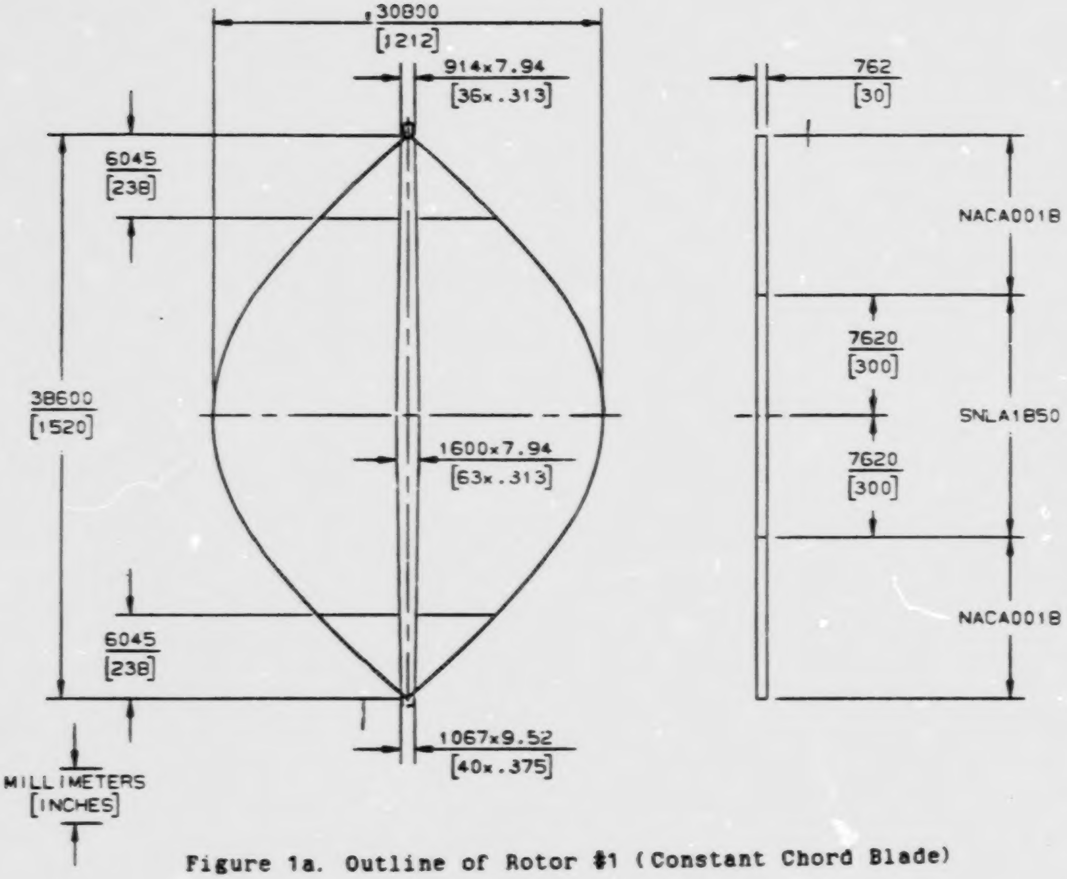
Outlines of the two configurations studied are shown in Figure 1. The first rotor has blades which can be made of a single aluminum extrusion and are therefore limited to approximately 30 inches (0.762 m). This, in turn, limits the size of rotor #1 due to the stresses that can be tolerated.

Whereas most of the connection details of rotor #1 are similar to those of the Indal 6400, rotor #2 has important differences. These are required due to the different blade chords and are due to the section of blade adjacent to the roots being made of a steel core with an airfoil fairing.

Some of the important features of the two new rotors are listed in Table #1 together with the estimated energy production under the two specified wind regimes. The performance curves of the Indal 6400 and the proposed rotor #2 are compared in Figure 2.

3. STRUCTURAL ANALYSIS

The structural analysis of each of the new rotors consisted of a natural frequency extraction, which was repeated until no resonances were predicted, a frequency response analysis (corresponding to operation in a 45 mph wind), and a nonlinear static survival wind analysis. All of the analysis on the operating rotor included the full effects of the rotating reference frame.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762
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6045
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NACA0018
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NACA0018
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1067x9.52
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Figure 1a. Outline of Rotor #1 (Constant Chord Blade)

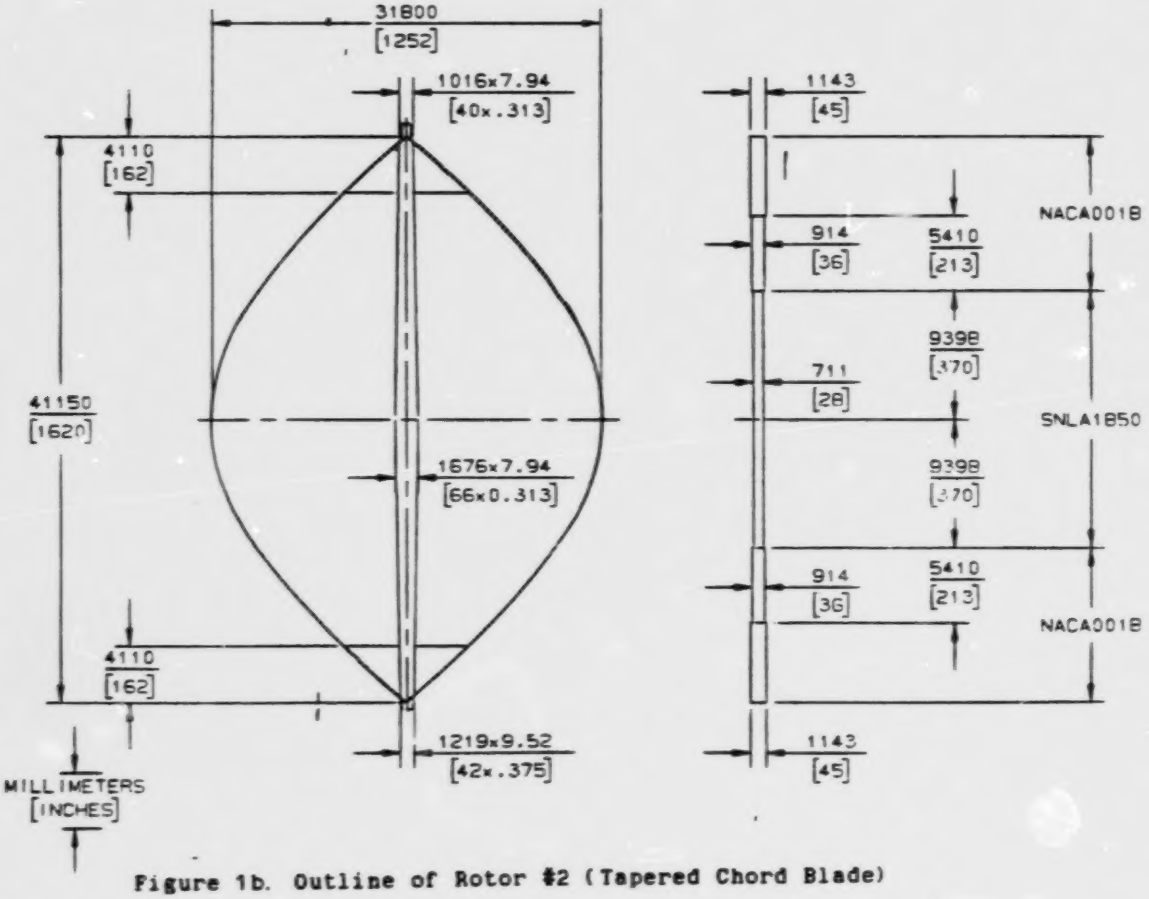
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Figure 1b. Outline of Rotor #2 (Tapered Chord Blade)

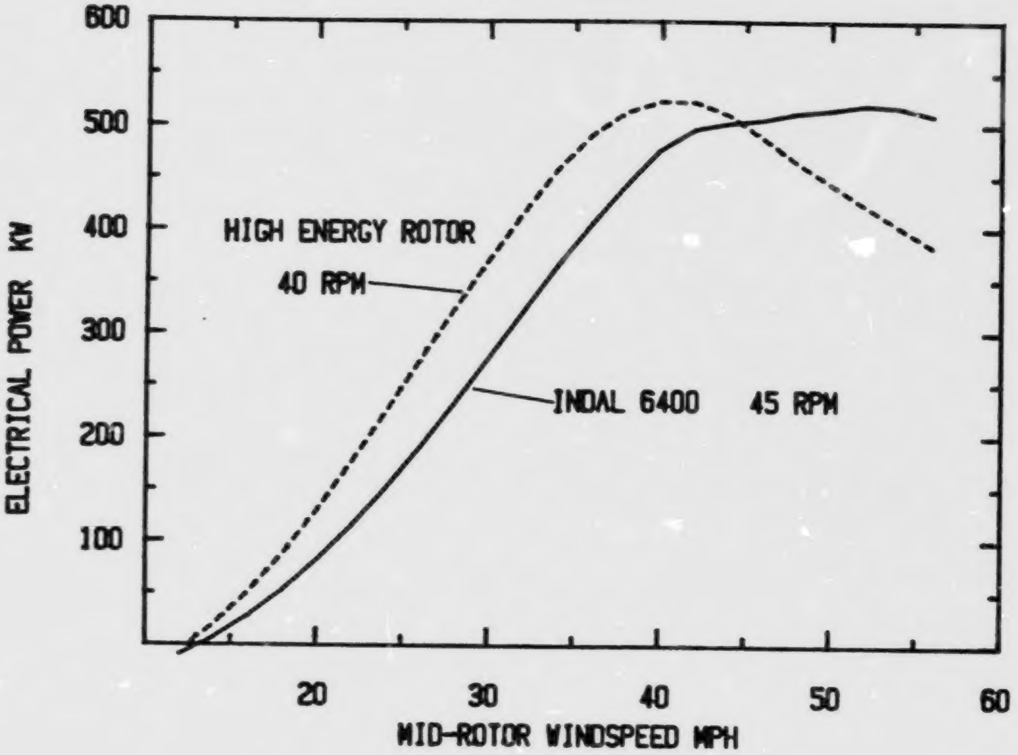

Figure 2. Performance of Indal 6400 and Rotor #2

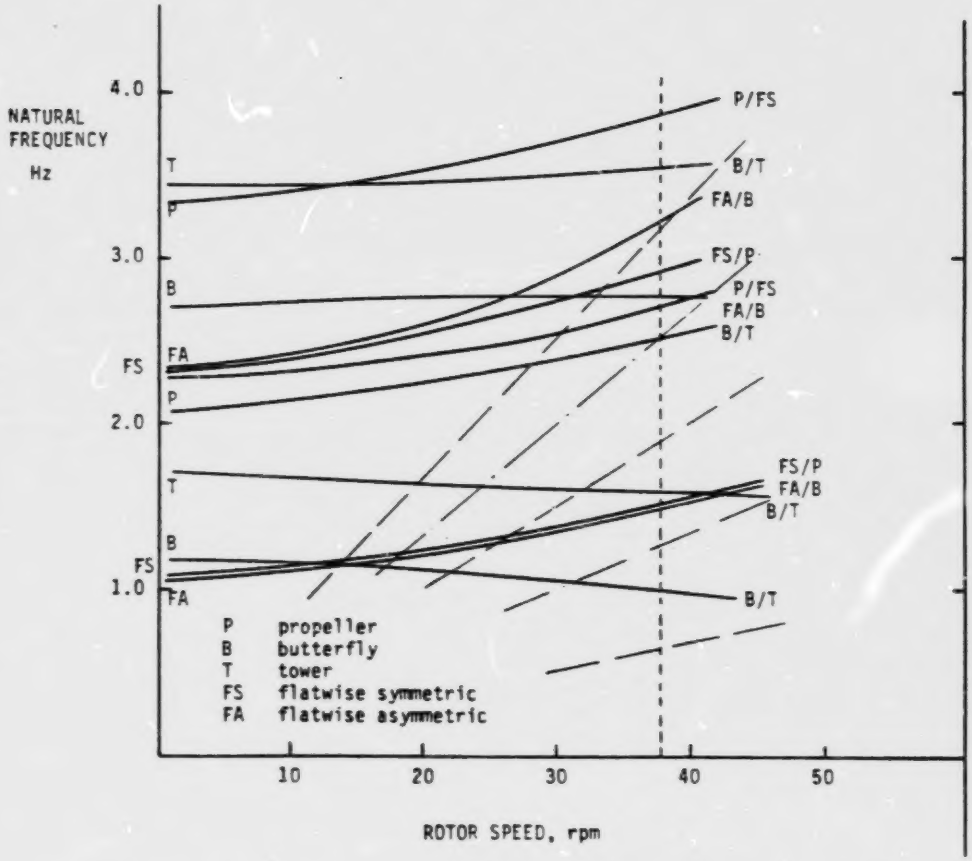

Figure 3. Natural Frequencies of Rotor #2 vs. Rotor Speed

The natural frequencies of the rotor are affected by the rotor speed; this is illustrated by Figure 3 which shows the natural frequencies of rotor #2 plotted against rotor speed. These natural frequencies are strongly influenced by the location and stiffness of any horizontal struts. The configuration must be modified to simultaneously satisfy the need to avoid resonant conditions, the reduction of operating fatigue stresses below a specified ceiling, and the minimizing of aerodynamic losses from drag on the struts.

It was necessary to include horizontal struts on rotor #1 at approximately 0.15 of the rotor height; this was needed to control fatigue stresses. This requirement did not apply to rotor #2 but struts at 0.10 of the rotor height were included for the following reasons: the root connection loads are reduced and shared with the forces at the strut-blade connection; some natural frequencies are increased; the designer has an important tool for tuning the machine.

The frequency response was carried out at one windspeed only because experience has demonstrated a fairly linear relationship between windspeed and rms of cyclic stresses. As an approximate guide it was established that the maximum rms stress in a 6061-T6 bolted connection at this windspeed should be 1800 psi (12.4 MPa). The predicted rms values of cyclic stresses in a 45 mph wind are presented in Table 2.

The values given in Table 2 are based on a fully aluminum section. For rotor #2 this will be replaced by a structural steel box which will extend from the root to the connection with the 0.914 m (36 in.) chord blade. This approach is possible for several reasons: the blade is nearly straight in this region and minimal forming will be needed; the smoothness of the fairing of this length is not critical since the relative airspeeds are low; connection of the steel box core to the root flanges and to the strut may be made of high strength steel bolts which are more reliable in fatigue loading; steel has superior fatigue strength to that of aluminum alloys; the flexibility of a steel core will be of advantage in minimizing stresses due to centrifugal action.

4. COST ESTIMATE

Costs were based on a single production of twenty machines and are in 1987 Canadian dollars. Taxes and overheads were included. Costs were divided into recurring and non-recurring classes. The latter included initial or once-only costs such as engineering design and jig and tool manufacture. Transportation, installation, electrical connection, site preparation and operating costs were included with the non-recurring costs. The final cost per machine is shown in Table 3.

TABLE 3. COST OF ENERGY SUMMARY

Item	Indal 6400	Rotor #1 Constant Chord Blade	Rotor #2 Tapered Chord Blade
Total Costs per Machine	$709,544	$749,517	$761,997
Cost Increase	0%	5.6%	7.4%
PEI Site			
annual energy, MWh	731	858	1,005
total costs/annual energy, $/MWh	971	874	758
Cost of Energy Decrease	0%	10%	22%
Magdalen Islands, Case A			
annual energy, MWh	980	1,152	1,329
total costs/annual energy, $/MWH	724	651	573
Cost of Energy Decrease	0%	10%	21%
Magdalen Islands, Case C			
annual energy, MWh	1,521	1,724	1,919
total costs/annual energy, $/MWh	466	435	397
Cost of Energy Decrease	0%	6.7%	15%

NOTE: Engineering design costs have not been included for any of the three machines. This allows a true comparison

For rotor #1 the only item that shows an appreciable cost increase over the Indal 6400 is the blades and connections. This is due to the greater length and weight of the blades. The struts incorporate the same hinge pin arrangement and the same precision machining is therefore necessary.

The recurring costs for rotor #2 are only slightly greater than for rotor #1. This is due to design modifications involving the steel core blade adjacent to the roots and the simpler strut-blade connection. These two cost reductions tend to offset the cost increases associated with a larger column and longer blades.

The non-recurring costs of tooling are somewhat greater for rotor #2 due to the addition of one extrusion die and the complexity of some blade splices. Adjustment has also been made for the greater on-site assembly time required.

5. CONCLUSIONS

The overall cost effectiveness of a project will depend on the manner in which the project is financed and the payment received from energy sales. However, the relative merits of the three rotors may be judged by dividing the total costs per machine by the annual energy produced by that machine.

This has been done for all machines and locations in Table 3. This table shows that the cost of energy will be reduced by 22% if the Indal 6400 at PEI is replaced by rotor #2. The reduction is more modest in the very high wind site (Magdalen Island, Case C, 15%) and ranges from only 6.7% to 10% for rotor #1.

These results confirm trends that have already been noted. The greater cost effectiveness of the tailored airfoil rotors is most apparent in the lower wind regimes and those with Weibull distribution shape factors greater than 2.0 (such as trade wind sites). It is anticipated that in a typical trade wind site the cost of energy could fall by as much as 30%. The cost decrease at the PEI site would have been greater if the Weibull shape factor had been greater than the 1.68 value reported.

The marked superiority of rotor #2 over rotor #1 is due to two factors: one is the considerably greater energy production, and the other is the relatively small increase in production costs. The latter may be traced to the savings at the strut-blade connection and to the steel-core blade used near the roots.

The major conclusion of this study is that it is necessary to use the larger swept area and superior power coefficients of the tapered chord blade to obtain appreciable reductions in the cost of energy. Any further design work should therefore concentrate on rotor #2.

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THE INFLUENCE OF VORTEX FLAPS AND LEADING EDGE SNAGS ON THE PERFORMANCE OF DELTA-WING BLADED WIND-TURBINES

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ABSTRACT

A brief description is given of the concept of the delta-wing bladed rotor (abbreviated to delta-turbine). It is explained that this relatively new form of horizontal axis rotor is intended for water pumping applications. Delta-turbines employ flap-equipped, sharp-edged, fixed-pitch delta-wing like blades. The paper deals, specifically, with the influence, on rotor performance, of adding vortex flaps, and leading edge snags, to a delta-turbine. The influence on the aerodynamic performance of a single delta wing, mounted in a wind tunnel on a lift and drag balance, was first investigated using various vortex flaps and leading-edge-snag configurations prior to advancing to trials with a model, dynamometer equipped, wind-turbine rotor. Tests with a complete, 514 mm (20.25 in) diameter, model delta-turbine showed that performance benefits were obtainable with vortex flaps, deflected towards the blade pressure surface, located on the inboard edge of each blade and flap and also on the outboard edge of the flaps only. These additions to the model rotor increased the peak power coefficient from 0.36 to 0.39. An additional performance increment, resulting in a maximum power coefficient of 0.4, was obtained by adding leading edge snags to the outboard portion of each blade leading edge.

NOMENCLATURE

C	Maximum chord of the basic delta-wing (Fig. 2)
C_D	Drag coefficient: Drag/$\{\frac{1}{2}\ \rho\ U_\infty^2\ (\frac{1}{2}\ SC)\}$
C_F	Chord of trailing-edge flap (Fig. 2)
C_L	Lift coefficient: Lift/$\{\frac{1}{2}\ \rho\ U_\infty^2\ (\frac{1}{2}\ SC)\}$
C_P	Power coefficient: Turbine power/$\{\frac{1}{2}\ \rho\ U_\infty^3\ (\pi/4\ D^2)\}$
C_T	Torque coefficient: Turbine torque/$\{\frac{1}{2}\ \rho\ U_\infty^2\ (\pi/4\ D^2)(D/4)\}$
D	Diameter of turbine rotor
h	Height of vortex flap at delta-wing apex (Fig. 2)
s	Span of delta-wing (Fig. 2)
U_∞	Free stream velocity
α	Incidence angle of delta wing
λ	Turbine tip-speed ratio
ρ	Ambient density

INTRODUCTION

Wind turbines, especially suited for driving water pumps and other mechanical loads, employing delta-wing like blades have been under development for approximately a decade [1,2,3]. This work has resulted, in addition to the construction of models employed in wind-tunnel testing, in several full scale prototype machines the largest of which had a rotor of 16 m (52.5 ft) diameter [3]. This unit was also subjected to field testing and was found, via the method-of-bins, to have a peak power coefficient of 0.41 [4]. This value can be compared with a peak power coefficient of about 0.32 typical of classical multibladed turbines usually employed in water pumping wind-turbines [5]. Both conventional multibladed and delta-wing bladed turbines produce their maximum torque at zero rotor speed [5]. Figure 1 illustrates the basic arrangement of a delta-wing bladed turbine, or delta-turbine. It can be seen that each blade consists of two surfaces: a sharp-edged flat-plate delta wing plus a large flap-like surface attached to the trailing edge of the delta.

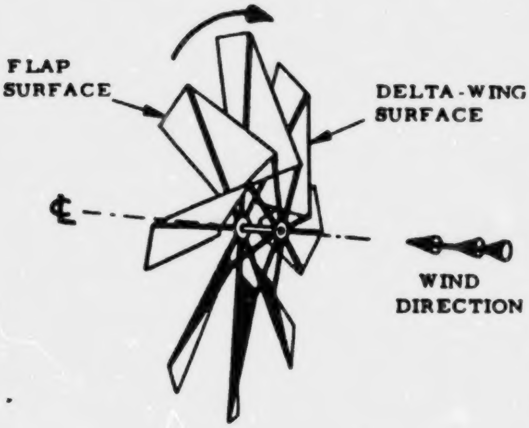

FIG. 1 BASIC ARRANGEMENT OF A DELTA-TURBINE

The purpose of the work described here was to investigate the influence, on delta-turbine performance, of vortex flaps, sometimes called maneuvering flaps, attached to the leading edges of the blades [6] and also other leading edge devices termed snags. In each case the aim was two-fold; to attempt to obtain improved performance whilst, at the same time, achieving some degree of structural reinforcement of the blade surfaces of delta-turbines. Since the structure of a delta-turbine is inherently simple, only very elementary additions to the blade surfaces, such as could be formed by bending or the attachment of simple cut-out forms, were considered for the implementation of the vortex flaps and leading-edge snags. In order to establish the influence on the aerodynamic performance of delta-wings of very simple vortex flap configurations and leading edge snags wind-tunnel tests were first conducted on an available flat plate, sharp-edged, model delta wing specially equipped with vortex flaps and, alternatively, leading edge snags. An existing model delta-turbine rotor was subsequently modified, on the basis of the results of the single-wing tests, to incorporate vortex flaps and leading-edge snags.

TESTS OF SINGLE DELTA-WING

Vortex flaps are, essentially, small flat-plate extensions of the leading edges of delta-wings which, in aircraft applications, can be deflected to project above, or below, the surface of a delta-wing. These can significantly modify the flow over the wing. For the work described here only fixed vortex flaps were of interest mounted at right angles to the plane of the wing surface. Figure 2 illustrates the vortex flap configurations wind-tunnel tested on an isolated sharp-edged, flat plate delta-wing of aspect ratio 2. Figure 2(a) shows the basic, flat plate, delta-wing configuration. The approximate Reynolds number applicable to the single-wing tests, based on the mean chord of the delta wing and the free-stream velocity, was 9.4×10^4. The wind tunnel tests were carried out in an open-jet wind tunnel;

since the blockage of the jet was always less than 5% no blockage correction was applied.

Vortex Flaps

The aerodynamic performances obtained with the configurations of Fig. 2(b) and 2(c) are presented in Fig. 3, which shows lift coefficient, C_L, versus the indicated incidence angle α, and Fig. 4 which presents the corresponding drag coefficient versus incidence angle relationships. It can be seen from Fig. 3 that $dC_L/d\alpha$ is lower, as is the maximum value of C_L, with the vortex flaps projecting above the wing suction surface (Fig. 2(b)). The corresponding drag coefficient is, as can be seen from Fig. 4, generally greater with the configuration of Fig. 2(b). It is, therefore, clear that the wing efficiency, as identified by the lift-to-drag ratio, is poorer for the configuration of Fig. 2(b) than for that of Fig. 2(c). Figures 5 and 6 summarise the lift and drag situations, respectively, for the Fig. 2(b) and 2(c) configurations. The performance of the plain delta-wing (Fig. 2(a)) has been added for comparative purposes. In each case the curves of Fig. 5 and 6 are plotted for an effective angle of incidence for which $\alpha \equiv 0°$ when $C_L = 0$.

It can be seen, from Fig. 5, that $dC_L/d\alpha$ is essentially the same for the plain delta wing (Fig. 2(a)) and for the Fig. 2(c) configuration whilst the maximum value of C_L is approximately 18% greater for the latter. It can also be seen that the maximum C_L value occurs at an incidence angle of about 42° for the Fig. 2(c)

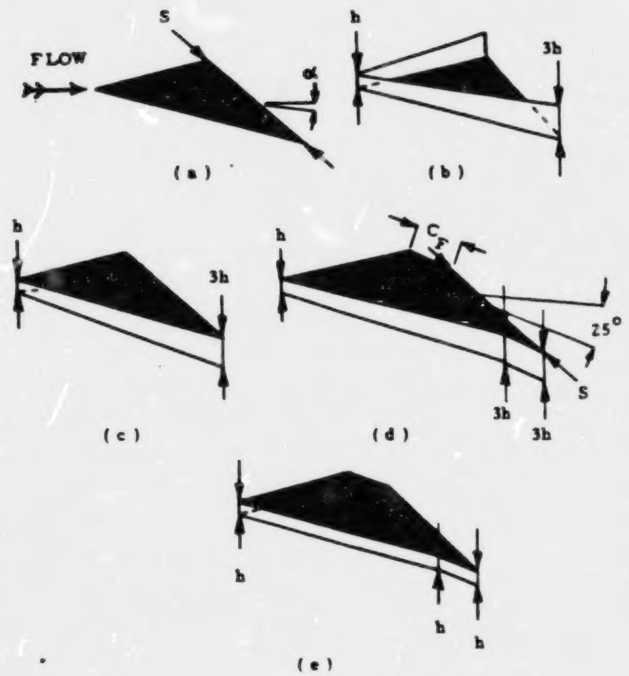

FIG. 2 DELTA-WING VORTEX-FLAP CONFIGURATIONS WIND-TUNNEL TESTED ($C = S$, $h = 0.03\ S$, $C_F = 0.2\ S$)

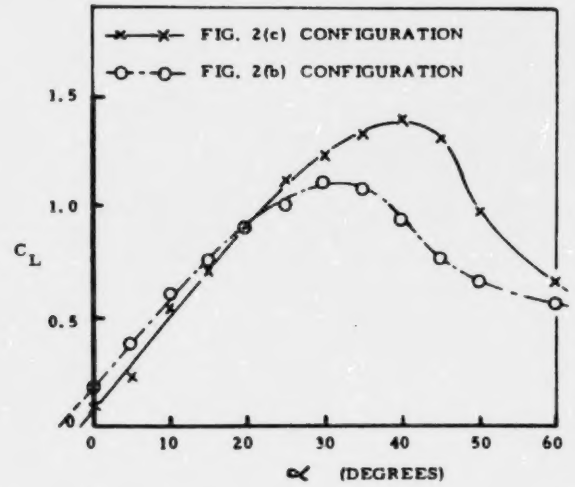

FIG. 3 LIFT COEFFICIENT VERSUS INCIDENCE ANGLE: PLAIN DELTA-WING WITH VORTEX FLAPS

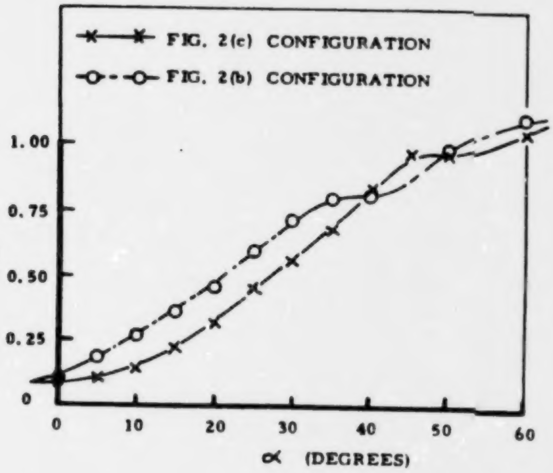

FIG. 4 DRAG COEFFICIENT VERSUS INCIDENCE ANGLE: PLAIN DELTA-WING WITH VORTEX FLAPS

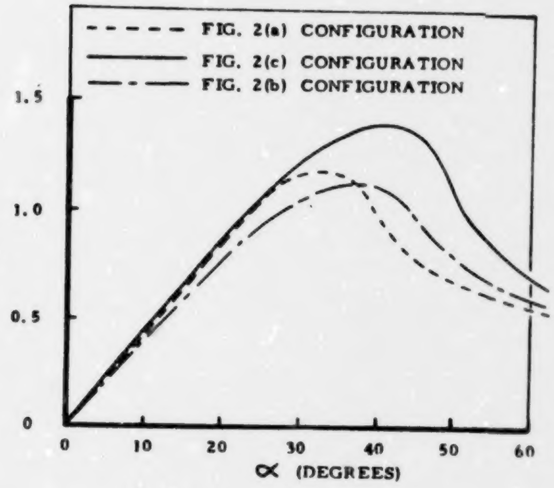

FIG. 5 LIFT COEFFICIENT COMPARISON WITH AND WITHOUT VORTEX FLAPS

configuration whereas the corresponding incidence angle is approximately 33° for the plain delta wing. From a comparison of Fig. 5 and 6 it can be seen that the C_L/C_D = lift/drag ratio is better, when $\alpha > 15°$, for the Fig. 2(c) configuration than for the plain delta wing (Fig. 2(a)). The lower value of C_D (Fig. 6) for the Fig. 2(c) configuration for $\alpha > 15°$ is attributed to leading edge suction resulting from flow over the vortex flaps [6]. It is also clear, however, that the drag of the wing is increased substantially for $\alpha < 15°$. This suggests that vortex flaps are not helpful for delta wings operating at small incidence angles.

Vortex Flaps Plus Trailing-Edge Flaps

Since a delta-turbine employs a trailing-edge flap on each blade it is important to verify that the benefits of vortex flaps projecting above the pressure surface of a delta wing are still realisable when the delta-wing is provided with a trailing-edge flap. The two configurations tested using vortex flaps in combination with a trailing-edge-flap equipped delta-wing are illustrated in Fig. 2(d) and 2(e). The essential difference between the configurations of Fig. 2(d) and 2(e) relates to the height of the vortex flaps. In the case of the Fig. 2(d) configuration the vortex flap height increases from h at the apex of the delta wing to 3 h at the trailing edge. This vortex flap arrangement is, therefore, in conformity with those of Fig. 2(b) and 2(c). For Fig. 2(e) the flap height is maintained constant at the value h; a flap of this comparatively modest height should be easier to implement structurally on a delta-turbine than one of much greater height.

Figure 7 shows the C_L versus α relationships obtained when a trailing-edge flap is incorporated in the delta wing. The dotted curve represents the

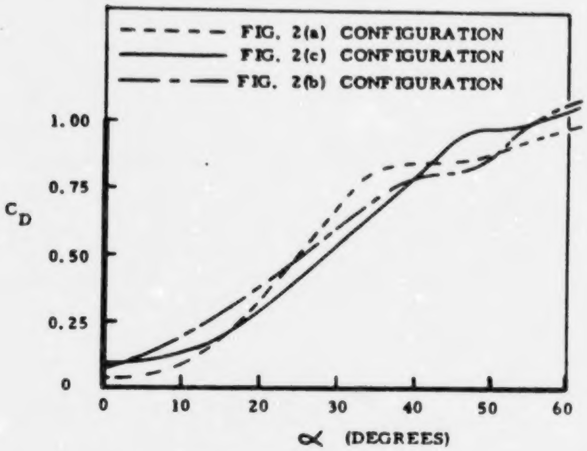

FIG. 6 DRAG COEFFICIENT COMPARISON WITH AND WITHOUT VORTEX FLAPS

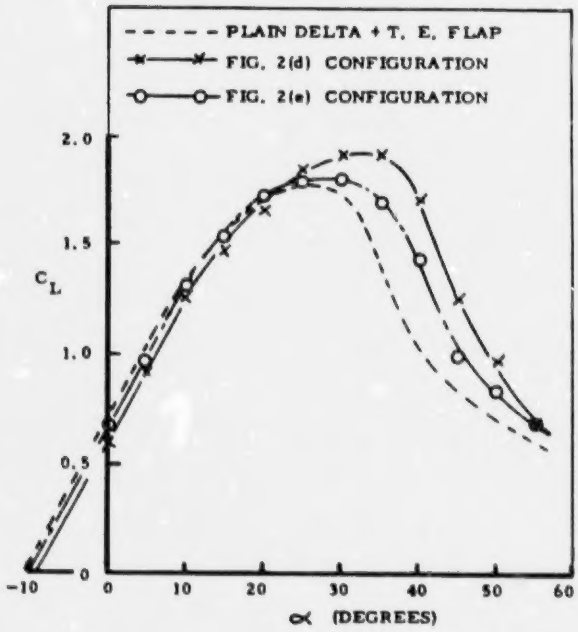

FIG. 7 LIFT PERFORMANCE OF DELTA-WING WITH TRAILING-EDGE FLAP AND VORTEX FLAPS

performance of the trailing-edge-flap equipped delta wing without the application of vortex flaps. It can be seen that, in general, the behaviour with vortex flaps has a similar character to that noted previously with respect to the configurations of Fig. 2(a) and 2(c). This general characterisation follows through when the corresponding C_D versus α relationships, shown in Fig. 8, are also considered. It is clear, from Fig. 7 and 8, that both the benefits and disadvantages of vortex flaps are diminished when the relatively low, uniform, height vortex flaps of the configuration of Fig. 2(e) are employed.

Leading-Edge Snags

An aerodynamic device which works in a somewhat different manner from a vortex flap is a leading-edge snag. This is fairly commonly used on delta, and highly swept, aircraft wings. It takes the form of a step or "snag" in the wing leading edge rather in the manner illustrated in Fig. 9 which shows the plain delta-wing (Fig. 2(a)) with leading edge snags added. For most aircraft applications the leading edge sweep angle is maintained constant throughout. In the case of the configuration shown in Fig. 9 the leading edge sweep angle is increased due to the presence of the add-on snag surfaces. Examples of aircraft employing leading-edge snags are the Dassault Etendard, IAI Kfir, McDonnell Douglas F18 Hornet and the McDonnell Douglas F.4 Phantom [7].

The test results obtained using the leading-edge snags shown in Fig. 9 are presented in Fig. 10 and 11. It is usually accepted that the apex of a snag serves as an additional vortex generator thereby originating an additional, essentially streamwise, vortex to that originated at the apex of the

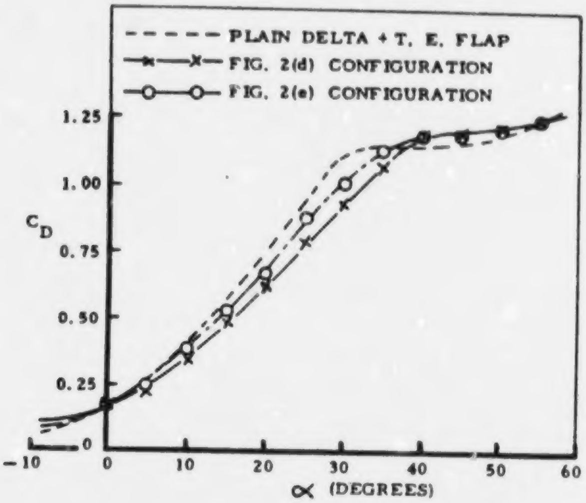

FIG. 8 DRAG COEFFICIENTS OF DELTA-WING WITH TRAILING-EDGE FLAP AND VORTEX FLAPS

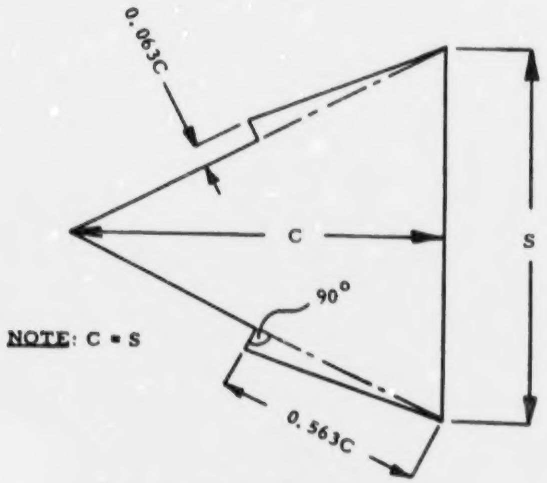

FIG. 9 DELTA-WING WITH LEADING-EDGE SNAGS

delta wing. Because of this it could be expected that $dC_L/d\alpha$ of the wing will tend to be increased. This feature is observable from Fig. 10, a plot of C_L versus α. The use of snags appears to provide very little benefit at high incidence angle and, generally, the snags tested produced far less dramatic results than those observed when using vortex flaps. However, the beneficial influences of snags are, unlike those of vortex flaps, manifest at small incidence angles typically less than about 10°. It can be seen from Fig. 10 and 11 that the lift/drag ratio is slightly better, at very small incidence angles, when snags are employed which are deflected, about the wing leading edge, towards the suction surface of the delta. The deflection angle employed was 20°. The very slightly improved C_L values at high angles of incidence appear merely to reflect the small increase in wing area due to the presence of the snags.

TESTS OF MODEL DELTA-TURBINE

An attempt was made to retrofit an existing, dynamometer equipped, model delta-turbine with vortex flaps and leading-edge snags. The essential lesson with respect to vortex flaps was that they appear to be beneficial at high angles of incidence but disadvantageous at low incidence. The opposite appeared to be the case for leading edge snags. Accordingly the turbine was modified to include vortex flaps only on the radially inboard edge of the delta-wing like blade surfaces where, due to the locally low velocity ratio, the local incidence angle tends to be large. Vortex flaps were also added to the outboard tips of the flap surfaces only since it appears that the presence of vortex flaps allows a higher pressure to be developed on blade pressure surfaces than is otherwise the case. The flap outboard tip application should not engender a major drag penalty.

Because, over much of the turbine operational regime, the outboard portion of the delta-wing like blade surfaces operate at small, or even negative,

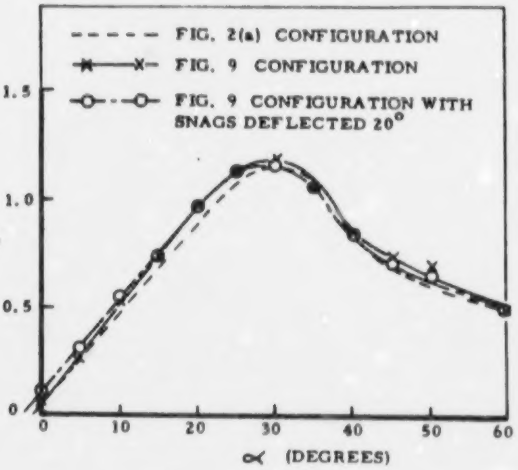

FIG. 10 LIFT PERFORMANCE OF DELTA-WING WITH LEADING-EDGE SNAGS

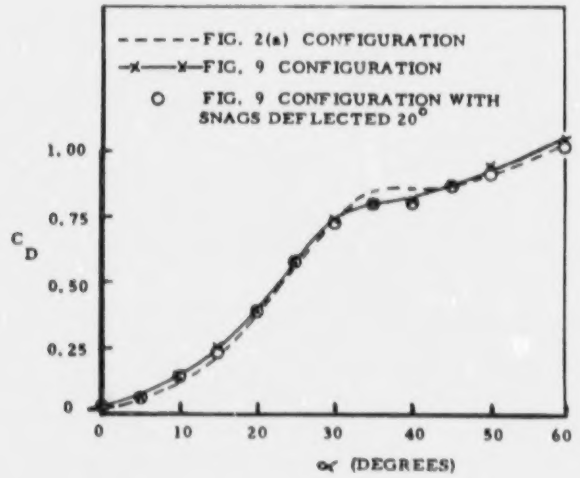

FIG. 11 DRAG COEFFICIENTS OF DELTA-WING WITH LEADING-EDGE SNAGS

incidence angles it appeared that leading edge snags could likely be applied to these regions with the hope of achieving small performance benefits. The final turbine configuration is shown in Fig. 12. Separate wind-tunnel tests were arranged to establish the influence on performance of each additional surface.

With Vortex Flaps

The first tests were conducted with vortex flap-like surfaces added to the outboard tips only of the blade trailing edge flaps. These surfaces are illustrated in Fig. 12 and the results obtained are presented in Fig. 13. Subsequently vortex flaps were added to the inboard edges of the delta-wing and flap surfaces. Again the configuration was as shown in Fig. 12. A further, small, improvement in performance resulted as indicated in Fig. 13. The dotted curve of Fig. 13 shows the performance prior to adding the vortex flap surfaces. It can be seen that the peak power coefficient increased by just over 8% from 0.36 to 0.39. The runaway tip speed ratio increased from 3.07 to 3.2.

With Vortex Flaps Plus Leading-Edge Snags

Leading-edge snags, as shown in Fig. 12, were added to the outboard portions of the blade delta-wing surfaces. This modification gave a small additional improvement in performance resulting in a peak power coefficient for the model rotor, which was only of 514 mm (20.25 in) diameter, of 0.40 with an unaltered runaway tip speed ratio of 3.2. The maximum power coefficient was thus increased by a total of 11% relative to that of the unmodified model. Figure 14 shows the power (C_P) and torque (C_T) coefficients versus tip speed ratio (λ) for the original (dotted curves) and fully modified version of the rotor.

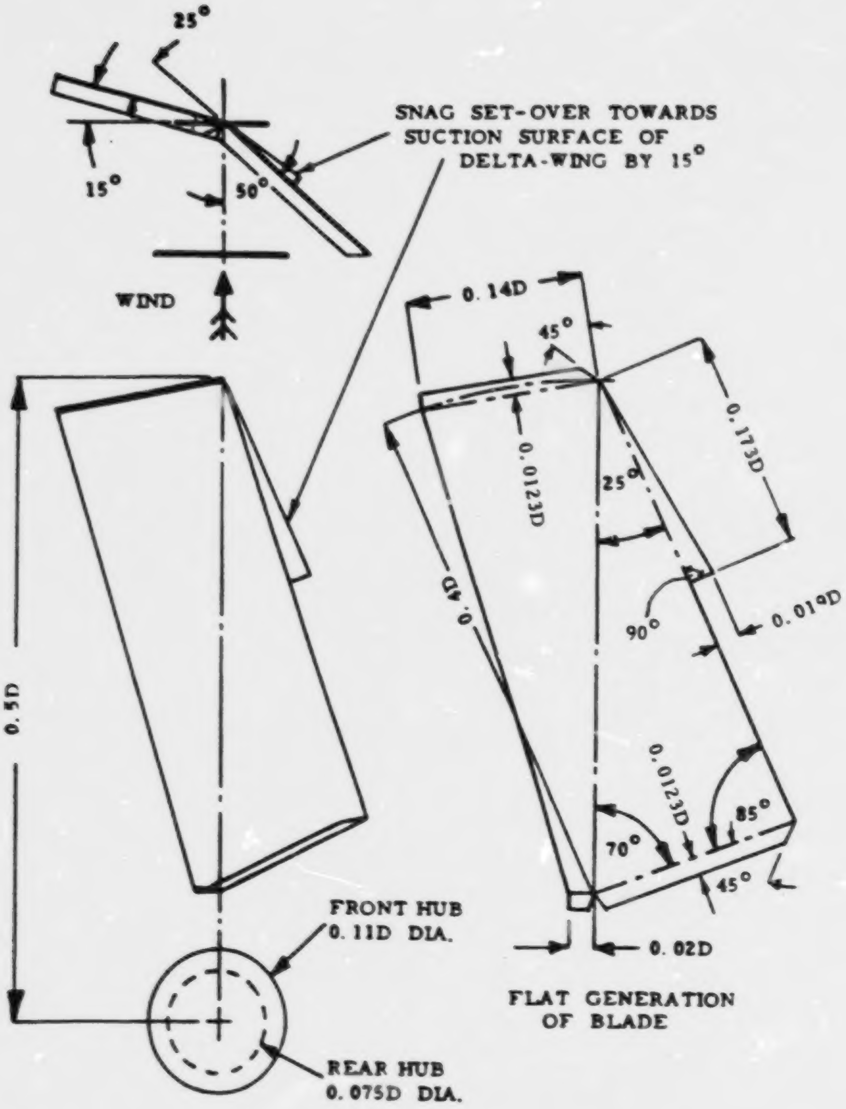
25°
SNAG SET-OVER TOWARDS SUCTION SURFACE OF DELTA-WING BY 15°
15°
50°
WIND
0.14D
45°
0.173D
0.0123D
25°
0.4D
0.019D
90°
0.5D
0.0123D
85°
70°
45°
FRONT HUB 0.11D DIA.
0.02D
FLAT GENERATION OF BLADE
REAR HUB 0.075D DIA.

FIG. 12 CONFIGURATION OF ONE BLADE OF MODIFIED DELTA-TURBINE EQUIPPED WITH VORTEX FLAPS AND LEADING-EDGE SNAG

DISCUSSION

It would appear that other rotor performance characteristics are possible than those presented in Fig. 14 which represent something of a compromise the intention being to maintain a high starting torque whilst, at the same time, improving the maximum value of the power coefficient. It seems probable that an alternative possibility would have been, as a result of a more extensive use of vortex flaps, to obtain a significantly improved starting torque at

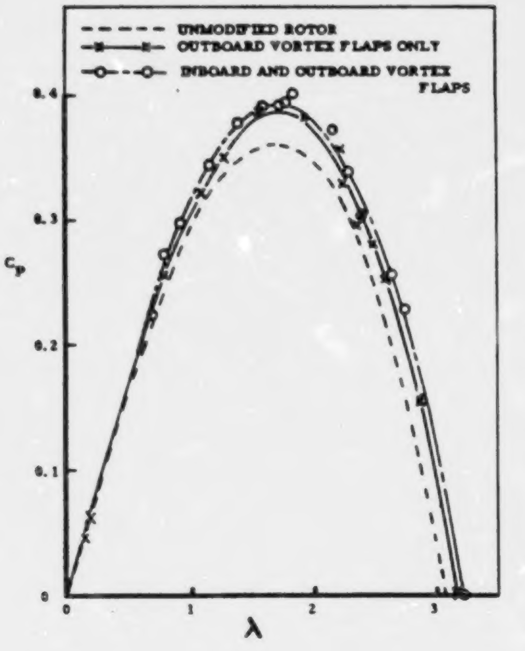

Fig. 13 PERFORMANCE OF TURBINE EQUIPPED WITH VORTEX FLAPS

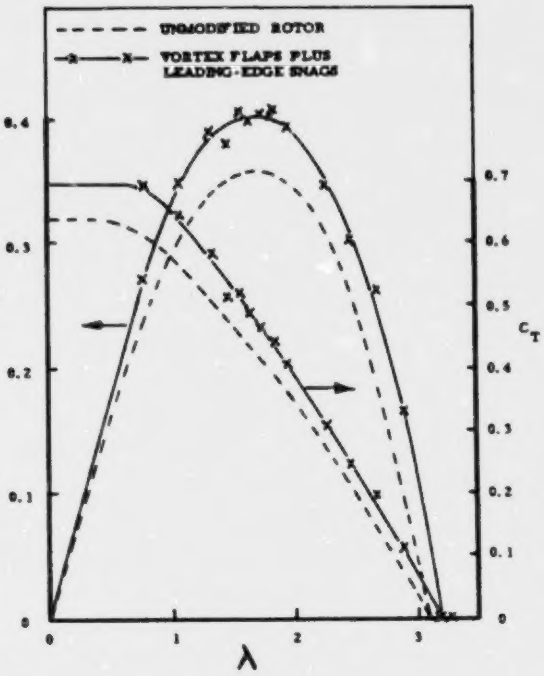

FIG. 14 PERFORMANCE OF TURBINE EQUIPPED WITH VORTEX FLAPS AND LEADING-EDGE SNAGS

the expense of maximum power coefficient.

It is also clear, from Fig. 7 and 8, that the height of vortex flaps is, at least over a range of heights, proportional to their effectiveness. The height of the vortex flaps built into the model rotor was significantly less than that corresponding to maximum effectiveness. The choice of a lower than optimum flap height was based on a consideration of the rotationally induced bending moment acting on the vortex flaps. Relaxation of such a consideration may result in yet greater benefits being obtainable from vortex flaps.

CONCLUSIONS

Various vortex flap and leading-edge snag configurations were wind-tunnel tested on a flat plate, sharp-edged, delta wing. The improvements in wing aerodynamic performance obtained from these tests were noted and an existing, dynamometer equipped, model delta-turbine was modified appropriately and subsequently wind-tunnel tested. An increase of 11% was obtained in the maximum power coefficient of the rotor, as a consequence of the modifications incorporated, resulting in a value of 0.40 for the small model turbine. The tip-speed ratio at the runaway condition was increased by approximately 4%, from 3.07 to 3.2, as a result of the modifications. The starting torque of the modified turbine was found to be about 9% greater than that of the original, unmodified, version: in both cases maximum torque was achieved at zero rotor speed. It was also noted that the vortex flaps and, to a lesser extent, the leading-edge snags serve also as turbine-blade structural reinforcements.

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FATIGUE ANALYSIS PROGRAM FOR WIND TURBINES

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ABSTRACT

A software program to estimate the lifetime of a wind turbine structure, based on actual stress data, rainflow counting, and Miner's Rule was developed by the National Research Council and DMR Group, a software company, of Ottawa. The statistical method of analyzing stress data for fatigue lifetime estimates called "RAINFLOW" has distinct advantages over methods employing spectra and average peak stress data, as these methods do not include stress excursion, speed variation, or turbulence effects on the structure which are inherently included in the rainflow methodology. Because of the non-linear aspects of fatigue damage accumulation, turbulence effects are believed to cause a substantial reduction in the life expectancy of wind turbine structures.

This paper describes the software algorithm employed, along with examples of the programs' various graphical displays and tabulated results. Actual calculations from the Indal Technologies first generation 500 kW turbine are presented. This turbine, located at the Atlantic Wind Test Site in Prince Edward Island, experienced a fatigue failure near the upper strut-blade connection after approximately 3000 hours of generating time. The fatigue life program was validated using data obtained a few weeks before the blade failure. The effects of the average wind speed, the Weilbull factor 'K', and cut-out wind speed on the life expectancy of the turbine are discussed.

KEYWORDS

Fatigue life prediction, testing wind turbines, rainflow

INTRODUCTION

The basic philosophy of the software program is quite simple. Statistical records of the dynamic stresses using rainflow are recorded for various points in the operating range of the wind turbine. The advantage of the statistical approach to the stress analysis is that frequency components, stress excursions and other non-linear components remain represented throughout the process. Another significant advantage is that these statistical records can be made to represent any time period of turbine operation.

Once the rainflow data has been taken at the various windspeeds (operating points), there are two other pieces of information required to calculate the life expectancy.

The first is the proper S-N curve for both the material under test and the environment.

An S-N curve estimates for a particular material and environment the number of cycles to failure given the amplitude of the stress cycle. The most accurate method of obtaining this curve is by the actual testing of several blade sections at various stress ranges to failure. Tests should be carried out under the type of environnment to be encountered. For example, a salt environment will adversely affect the S-N curve.

The last piece of information required is an estimate of the annual operating hours of the wind turbine for each wind speed range in which there is a representing set of rainflow data. To estimate the annual operating hours of the wind turbine, the actual or proposed site's wind regime must be known.

The regime is described in terms of the average wind speed and the Weilbull 'K' factor. Using the Weilbull equation, the number of hours for each wind speed range can be calculated.

Using these three pieces of information and Miner's rule, the life expectancy can be easily estimated.

SOFTWARE DESCRIPTION

The fatigue life expectancy software is divided into three main programs:

1] RAINFL: This program performs the rainflow algorithm on specified stress channels and time series files, storing the statistical data in channel designated files.

2] RAPLOT: This program is strictly a plotting routine to check the rainflow data and for estimating any missing data.

3] FLIFE: The third program compiles the rainflow data for a specified channel, receives information on the wind regime and S-N curve, and then estimates the life expectancy.

RAINFL: Program to Perform Rainflow and Store Results

This program is designed to read NRC's "HSDAS" time series files and then perform the rainflow analysis on user selected channels (maximum of 10) in 300 second segments. The resulting count/stress histogram arrays are automatically stored into files designated by the name RAxxx where 'xxx' is the channel number.

Figure 1 shows the information that is eventually stored into each file. Information in the file is actually recorded in terms of sums rather than probabilities to allow addition of further data into the files. Additional information required to calculate the standard deviation of the data points is also recorded. The three dimensional array consists of the rainflow counts and their respective stress ranges along with the wind speed range in which the data was taken.

The rainflow algorithm looks at the stress/strain data and determines each closed hysteresis loop within the stress/strain data. It then measures the amplitudes, determining the stress range the loop falls within, and then adds a count in the respective 'bin'. When the set time period (300 seconds) of data has been processed, a statistical histogram is produced which represents the stress loading of the structural section measured as a function of the particular operating parameters of the turbine, (i.e. average wind speed, RPM, etc.). Figure 2 illustrates this methodology. The first figure shows a typical complex stress waveform with respect to time. The second figure shows the data reduced to an array by finding the minimum and maximum points in the waveform. The third diagram illustrates the closed hysteresis loops within the data. Rainflow sorts these closed loops by amplitudes to form the resulting histogram in the fourth figure. This histogram represents the stress waveform for the fixed time period shown. The time period chosen for the rainflow algorithm was 300 seconds. This represents about 200 turbine revolutions on the Indal 500 kw machine, which gives a good statistical representation while eliminating problems due to spatial error between the turbine and measurement anemometer. Care must be taken to choose a scan frequency high enough to properly catch the stress peaks and valleys. While the program can handle any number of scan frequencies, most of the data for Aquilo was analyzed at 20 Hz. Scan frequencies greater than 20 times the fundamental stress frequency have been found to be adequate.

RAPLOT: Program to Plot Rainflow Results

This program is exclusively used to plot rainflow results to confirm the compiled data is valid and to help the user to estimate missing data points before initiating the fatigue life estimate program, 'FLIFE'.

The program is divided into three parts, each one representing a different type of plot available.

The first section plots the compiled rainflow histogram of a specified channel and mid-bin windspeed. Since data is continuously added to the file as it is received by the 'RAINFL' program, the y-axis is given in terms of probability so comparisons can be made easily.

Figure 3 is a typical rainflow histogram for a blade leading edge stress. Points on either side of the bin value indicate one standard deviation width from the average bin data. This helps the user flag bad data and ensures consistency in the data. This is required before representing several thousand hours of operating time in the 'FLIFE' program.

The second plot available graphs the average standard deviation of the stress (dynamic component of stress) for each wind speed band against wind speed. Figure 4 is a typical plot of this. Lines each side of the data points indicate one standard deviation width from the data.

The average standard deviation of stress plotted against windspeed has proved very useful, especially for predicting stress levels at wind speeds not yet obtained. As seen in Figure 4, the stress level at higher wind speeds can be easily predicted and thus decisions on whether the turbine will operate safely in higher winds can be determined.

The third and last plot available consists of all of the compiled data for the selected channel plotted in a normalized form. Mr. Jack Templin of the National Research Council of Canada has noted that when each rainflow histogram is divided on the stress range scale by their respective average standard deviation and the counts are normalized to a fixed time period, all of the rainflow data tends to collapse onto one characteristic curve. Figure 5 illustrates this point. Shown is a typical blade's family of rainflow data plotted. Figure 6 illustrates a column stress channel's family of data points. Note the column stresses have distinctly different characteristic shape.

This characteristic collapse of data has proven to be extremely useful in recreating rainflow data at windspeeds not yet measured. By normalizing the rainflow data at one wind speed (by dividing by the respective standard deviation of stress) and multiplying this by the predicted standard deviation of stress of the desired wind speed, a set of new rainflow data is created. Using this method, the life expectancy of the turbine can be predicted well before all the rainflow data has been taken throughout the turbine's operating range.

FLIFE: Program to Estimate Fatigue Life Expectancy

The fatigue life program is laid out into four blocks.

1] The first section locates the rainflow data files which the user has specified, (by channel number). The program then asks the user for information to recreate any missing data, asking for the data to use and the estimated standard deviation of the missing stress data. The program requires data in 2 m/s ranges from 5 to 25 m/s. If a lower cut-out than 26 m/s is used on the turbine, one estimates the standard deviation for the undesired wind speed bands at 1 psi. This causes the program to calculate zero damage which is the same as if the wind turbine were not operating within those wind speed bands.

The program then allows the user to adjust the 'real' data using the same method. This is desired when the average wind speed for a band is not in the centre of the bin causing the data to be unrepresentative of the mid-bin wind speed. By estimating again the standard variation of stress at the mid-wind speed, the rainflow data is adjusted accordingly. The program now has a complete and accurate set of rainflow data.

2] The next section calculates the annual number of hours the turbine will operate in each wind speed band. To do this the user must input the average annual wind speed for the test anemometer height and the estimated Weilbull factor 'K'. Using the Weilbull equation the program then calculates the hours per year for each wind speed band.

3] The next portion of the program determines from the user which S-N curve to use. The program presently allows three choices. The first is for aluminum blade sections similar to the Indal 500 kw machine. The second is for steel bolted joints, similar to the blades on the 4 mw turbine, Eole. The third choice is for a user supplied curve. All curves take the form of LOG N = A + B*LOG S, where A and B are constants.

The first two curves have been supplied by the turbine manufacturers. For the aluminum blade S-N curve, data was obtained from tests on a simulated blade root connection. There is, therefore, some uncertainty in applying this curve to other blade sections.

4] The last section of the program uses all of the compiled information and Minor's rule to calculate the fatigue life expectancy. Minor's rule basically states that for each stress range, the fractional damage is the accumulated counts over the number of cycles to failure. When the sum of these fractions for all the ranges is equal to one, a failure will occur. Since the number of counts can be estimated annually for each stress range and wind speed, it becomes a matter of adding all the fractional damages up and inverting the value to give the estimated life expectancy in years.

Table 1 is the tabulated output from the program for each life expectancy calculation. Channel 17 is the position A3LE, the blade leading edge stress just below the upper strut.

Wind Speed Bin	Hours Per Year	Avg. Std. Dev.	Damage	Percent Damage
7	1484.67	425.00	.003747	.00981
9	1190.04	575.00	.008262	.02163
11	863.40	775.00	.017659	.04622
13	576.12	1000.00	.038329	.10032
15	357.04	1275.00	.066025	.17282
17	206.90	1625.00	.111622	.29217
19	112.65	1950.00	.136405	.35704

The fatigue life in years at channel 17 is 2.6 years. This was for an average equator wind speed of 7.40 m/s and a Weilbull factor of 1.68

TABLE 1

LIFE EXPECTANCY OF THE AQUILO ROTOR BASED ON SELECTED STRESS MEASUREMENTS (Nov. 1985)

Figure 7 illustrates the fatigue life time expectancy in years of various blade leading edge and mid-column locations on the Aquilo rotor structure. An average annual mid-rotor wind speed for the site using data from 1983-1985 (5) was estimated at 7.4 m/s with a Weilbull 'K' of 1.68. Data for the rainflow was gathered a few weeks before the blade failure on Nov. 15, 1985. Basically, the fatigue failure which occurred at the strut connection between A2 and A3 was primarily caused by a combination of stress risers in the blades due to two unsupported and undeburred holes drilled through the blades for the strut attachment and salt corrosion accelerating the crack growth (6). The turbine had logged about 3000 hours of generating time at the point the failure occurred. This is typically about one year's operation.

Under normal conditions the turbine probably would have operated the estimated 50% longer life, but it was operated for a few months in the summer of 1985 close to a resonance which reduced its life expectancy significantly. Because of this variance in operating conditions as well as the huge uncertainty of a fatigue life analysis and the large scatter encountered in the S-N data, these calculations are well within the accuracy possible.

EFFECTS OF AVERAGE WIND SPEED, WEILBULL "K" AND CUT-OUT WIND SPEED ON THE FATIGUE LIFE EXPECTANCY

Figure 8 illustrates the effects of changing the wind regime (thus the operating hours in the various wind speed bands) and the cut-out speed of the wind turbine. This data was obtained by selecting a strain gauge station, (in this case A3LE, a leading edge stress near the upper blade strut connection), and running the program "FLIFE" using different wind regimes. Cut-out wind speed was simulated by ignoring the stress data in higher wind speed bands. The standard operating parameters were chosen to be an average wind speed at the equator of 7.0 m/s with a Weilbull factor 'K' of 2.0 and a cut-out wind speed of 20 m/s. Using these parameters the life expectancy for A3LE was found to be about five years. The three plots in Figure 8 illustrate the life expectancy factor change by adjusting these various parameters. While these factors are dependent on the characteristic slope of the standard deviation of stress curve and the rainflow for various strain gauge locations, the overall trend and values are typical. The most sensitive parameter is the average wind speed. With the average wind speed of 7.0 m/s, the life expectancy is five years. By installing the wind turbine in a regime of 5.0 m/s this life expectancy becomes a respectable value of 40 years. On the other hand, by installing the turbine from the 7.0 m/s average wind speed to a 8.0 m/s wind regime, the life expectancy is halved, (to 2.5 years).

As with the average wind speed the Weilbull factor 'K' affects the number of hours per year the turbine operates in the damaging higher winds. The lower the 'K' value the more hours per year the winds are in the higher wind speed bands. Thus moving from a factor of 2.0 to 2.46 doubles the life expectancy of the stress joint. One of the more common mistakes is to assume a Weilbull 'K' factor of 2.0 for unknown wind regimes and then estimate fatigue life expectancy. The Atlantic Wind Test Site has an estimated Weilbull factor of 1.68. Life expectancy is reduced by an incredible 40% by changing the normally assumed Weilbull factor of 2.0 to 1.68.

The last parameter plotted is the effect of changing the cut-out wind speed using the standard operating wind regime of average wind speed of 7.0 m/s and a 'K' value of 2.0. The cut-out effects are very sensitive to the wind regime which dictates the number of hours operating at the damaging higher wind speeds. Thus the cut-out wind speed versus life expectancy factor curve would change drastically with the wind regime. The curve plotted does illustrate a typical response to changing the cut-out. One can see that the life expectancy can be doubled by reducing the cut-out from 20 to 16 m/s. The increased life expectancy would have to be weighed against energy lost due to a lower cut-out. The curve levels off as the cut-out is increased only because the operating hours in the higher wind speeds with this wind regime is so small. Since above 24 m/s winds there are virtually no operating hours, there is no subsequent damage.

Figure 9 is yet another way to help decide the best cut-out wind speed of a turbine. The figure shows the annual operating time, the energy, and damage for each wind speed band (2 m/s widths) as a fraction of the total. The interesting set of bars are at 19 m/s. Here the machine spends about 2% of its time operating between 18 and 20 m/s where it produces 7% of its energy and yet has inflicted 37% of the total damage.

If the fatigue life expectancy is well above the requirement, this is of no consequence, (i.e. if the life expectancy calculated to be 500 years, why worry about increasing it?).

However, if the calculated fatigue life was marginal or below economic payback one might want to do an economic study to improve the outlook. By changing the cut-out wind speed down to 18 m/s from 20 m/s the machine loses 7% of its annual income, (energy), but if its life expectancy before was 10 years, this would now increase to almost 14 years providing income for four more years than previously expected. Economically this might be a better solution.

The above algorithm might also be used on other marginal components which might be discovered whose characteristics might involve an almost constant damage for all winds, (i.e. bearings). In this case the cut-in might be made higher since the turbine operates 25% of the time in wind speeds between 4 and 6 m/s but produces less than 1% of the annual energy. These are some difficult questions which manufacturers have to ask themselves when dealing with damage and an efficient power producing plant.

DISCUSSION

The results presented clearly indicate there exists a substantial benefit to wind turbine manufacturers who use this simple analysis program to estimate the life expectancy of their turbine structures. Enough data can be gathered within a few hours, i.e. during a storm front, to estimate the life expectancy of the structure. The accuracy of the calculation is extremely sensitive to the accuracy of the S-N data used. To obtain reasonable results, actual blade fatigue data should be compiled and used. A corrosive type environment should also be assumed in most cases. The fatigue life expectancy results indicate that the wind regime to which the turbine is subjected can adversely affect the life expectancy. While a turbine may have a 40 year life expectancy at one site, this may be reduced to less than 10 years at another site due to differences in the wind regimes.

The program has also indicated there is an extreme non-linear relationship between fatigue damage and wind speed. Typical results have shown that even though a turbine operates less than 2% of its time between 18 and 20 m/s winds, greater than 35% of the overall fatigue damage can occur in this range.

These results indicate that some rethinking may be in order in the wind turbine industry to take advantage of this knowledge. More economic studies using fatigue damage calculations will help the manufacturer set an economically sound cut-out and cut-in wind speed.

With the substantially lower cost of blades in proportion to the rest of the wind turbine, fatigue life prediction may allow for scheduled blade replacement, or the throw-away blade, without losing months of valuable generating time.

In conclusion, it is felt that much more work could be done in this area with respect to S-N curve data, economics as related to fatigue damage, and the practical cut-in and cut-out wind speeds. This could help bring the wind turbine reliability factor up substantially.

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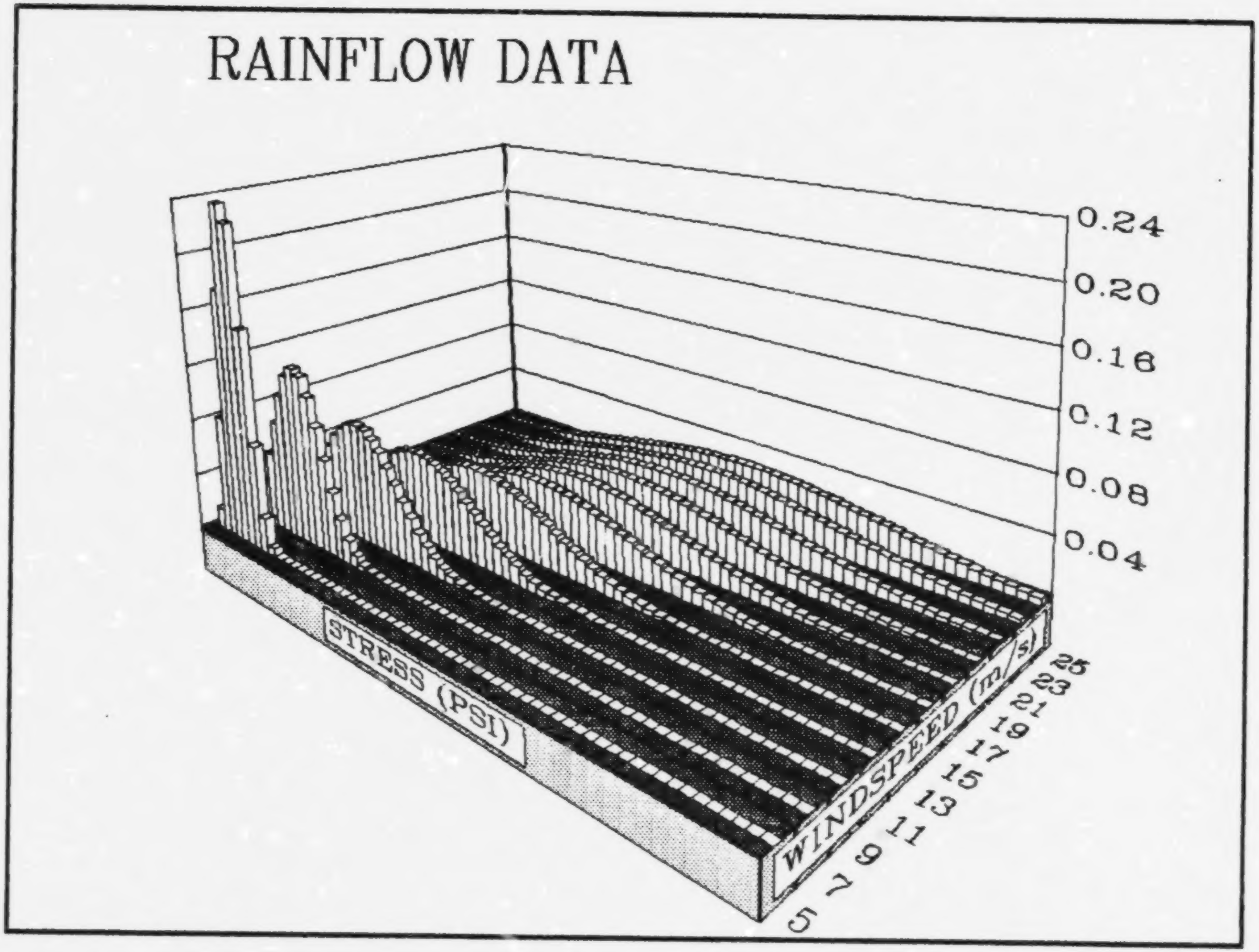


Figure 1: Three Dimensional View of Rainflow Data

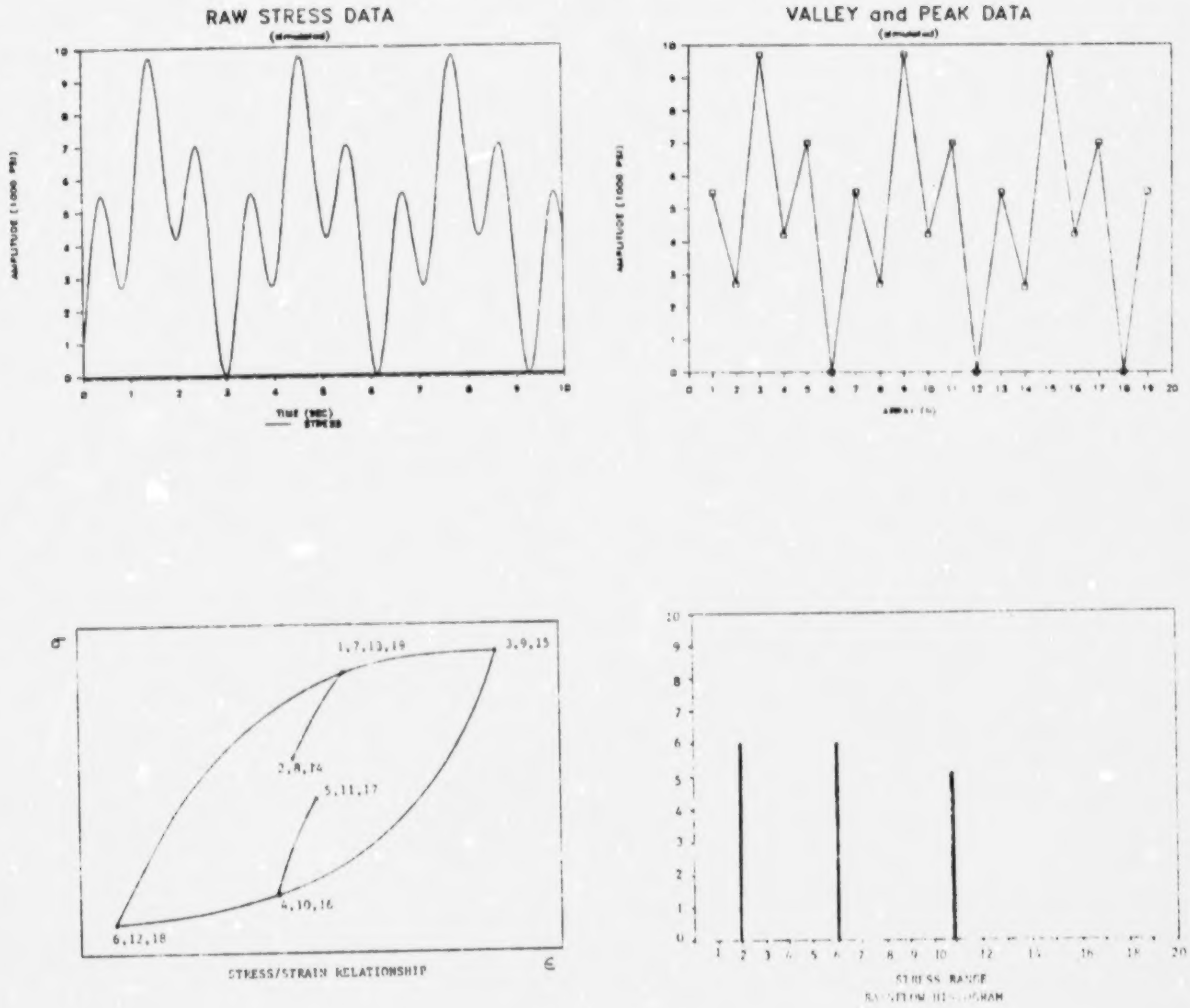
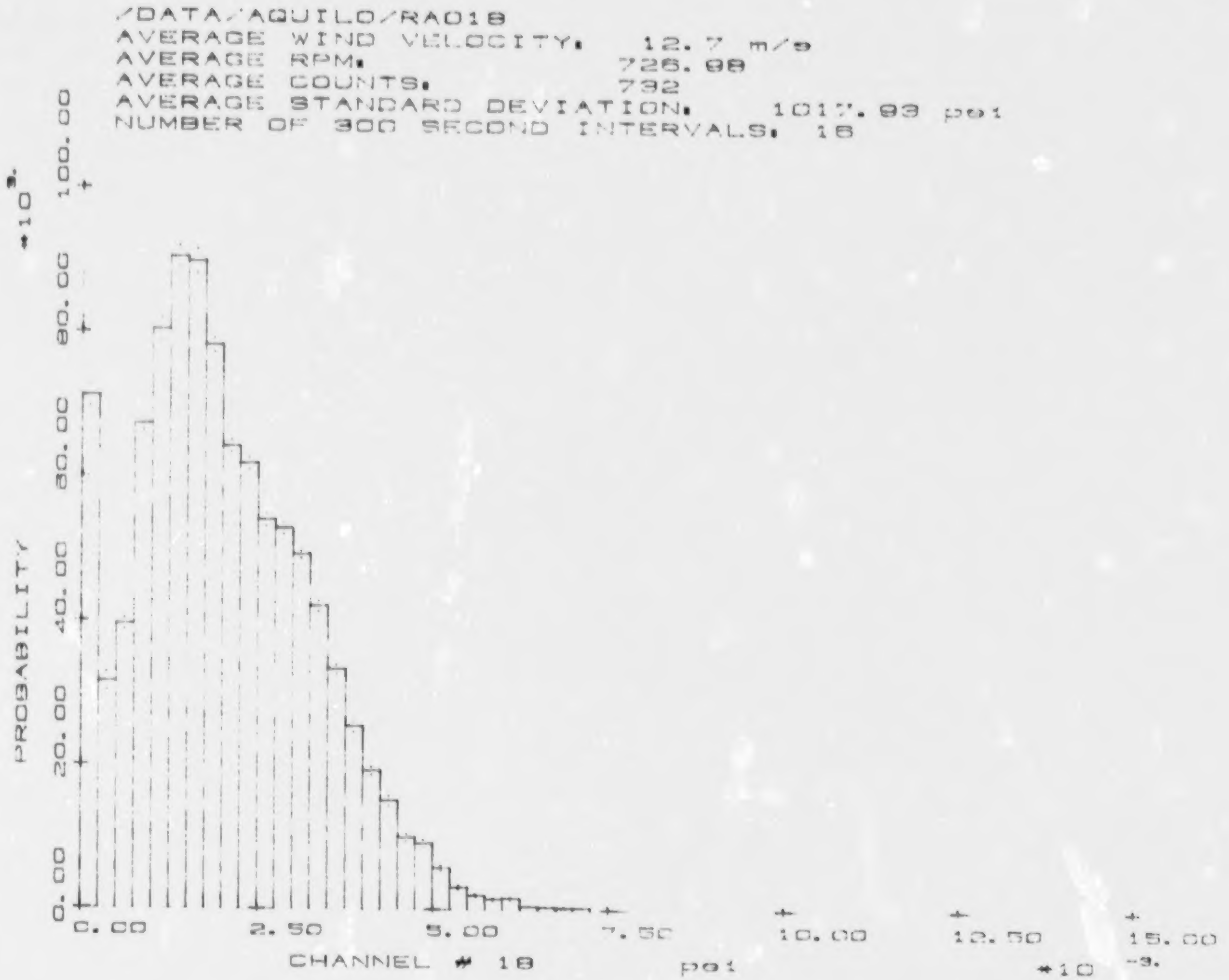


Figure 2: Rainflow Methodology



```
/DATA/AQUILO/RA018
AVERAGE WIND VELOCITY:   12.7 m/s
AVERAGE RPM:                 726.88
AVERAGE COUNTS:              792
AVERAGE STANDARD DEVIATION:     1017.93 psi
NUMBER OF 300 SECOND INTERVALS: 18
```

Figure 3: Typical Rainflow Histogram for Blade Leading Edge

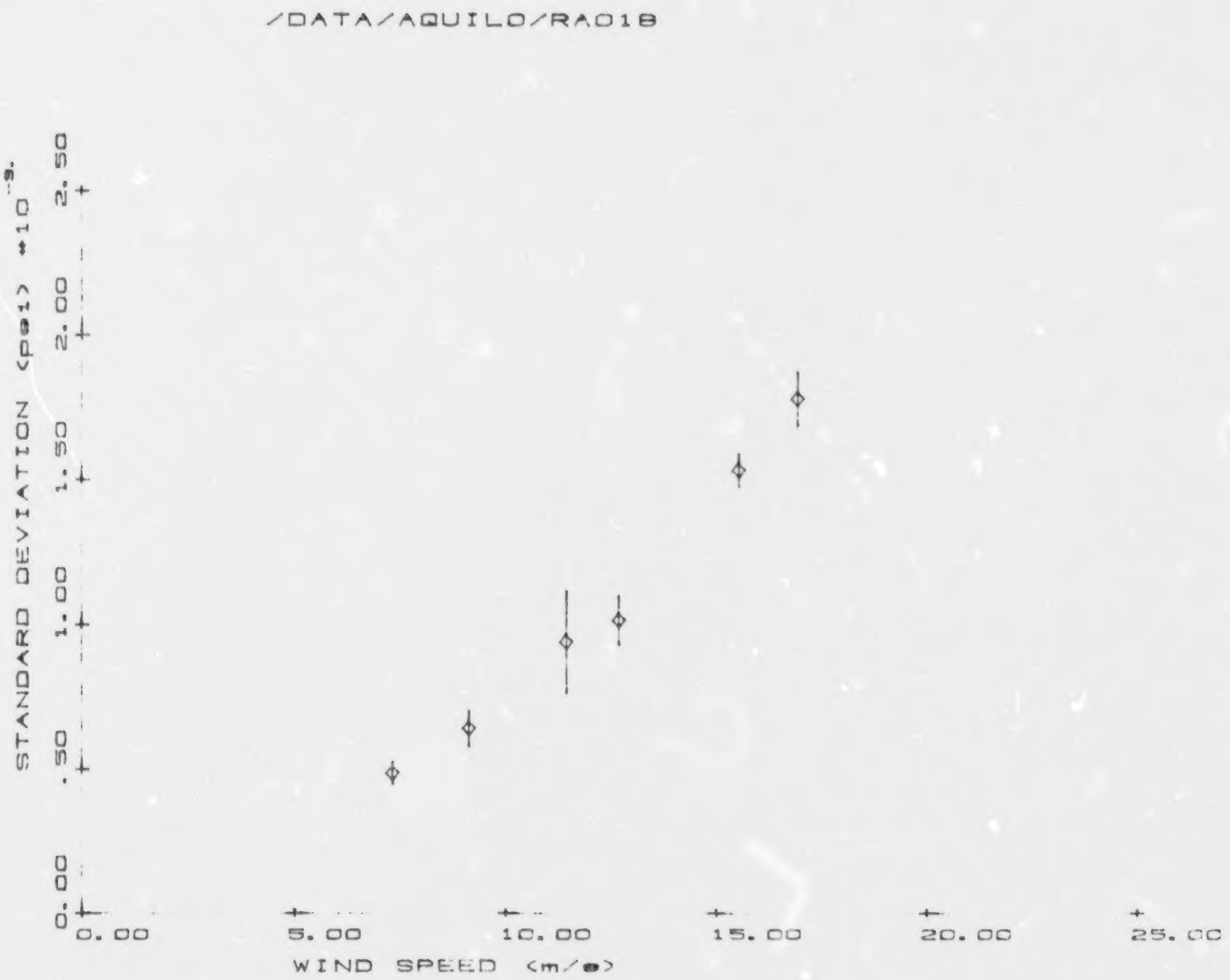


Figure 4: Typical Plot of Average Standard Deviation Versus Wind Speed for Blade Leading Edge

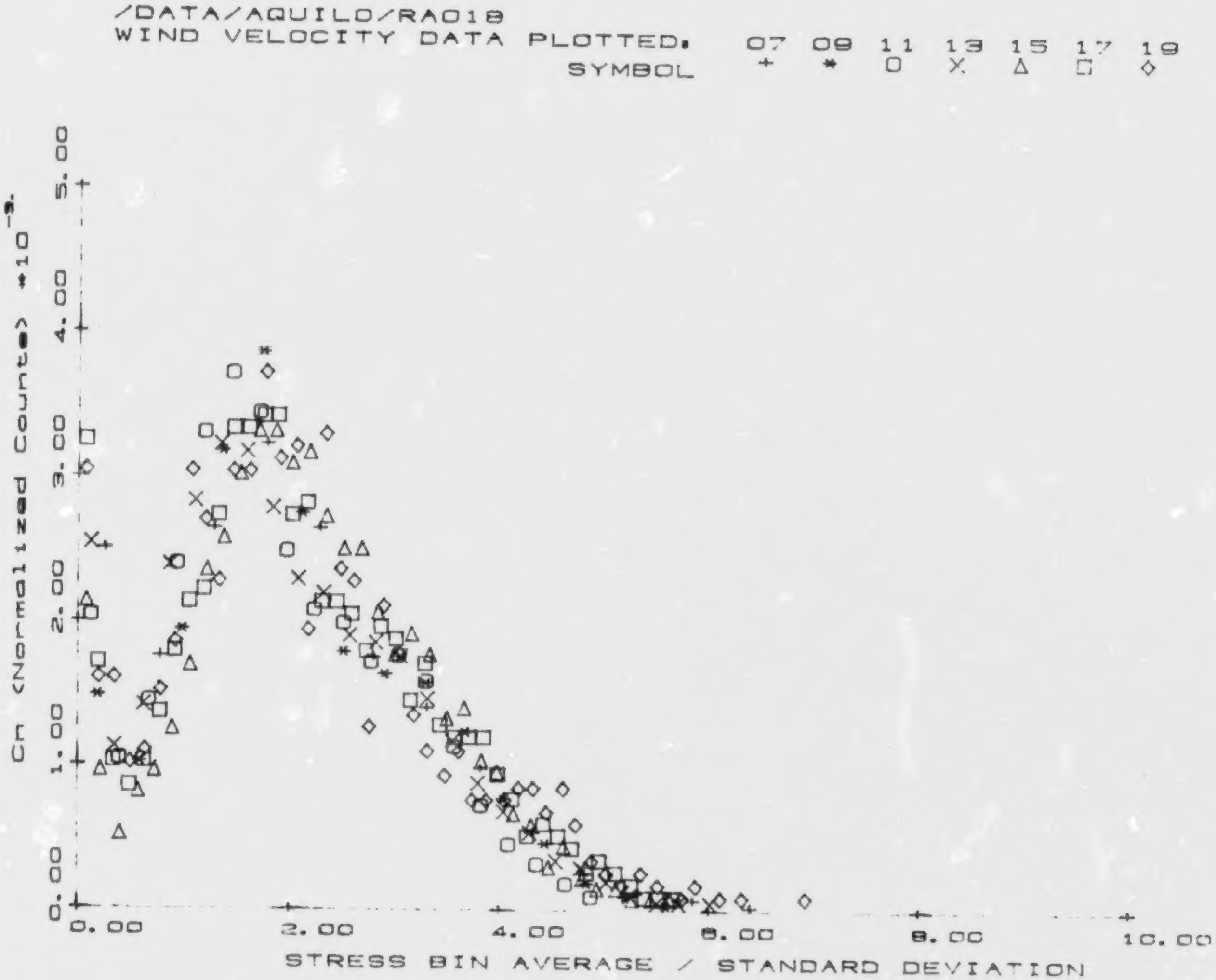


Figure 5: Normalized Rainflow Data for Blade Leading Edge

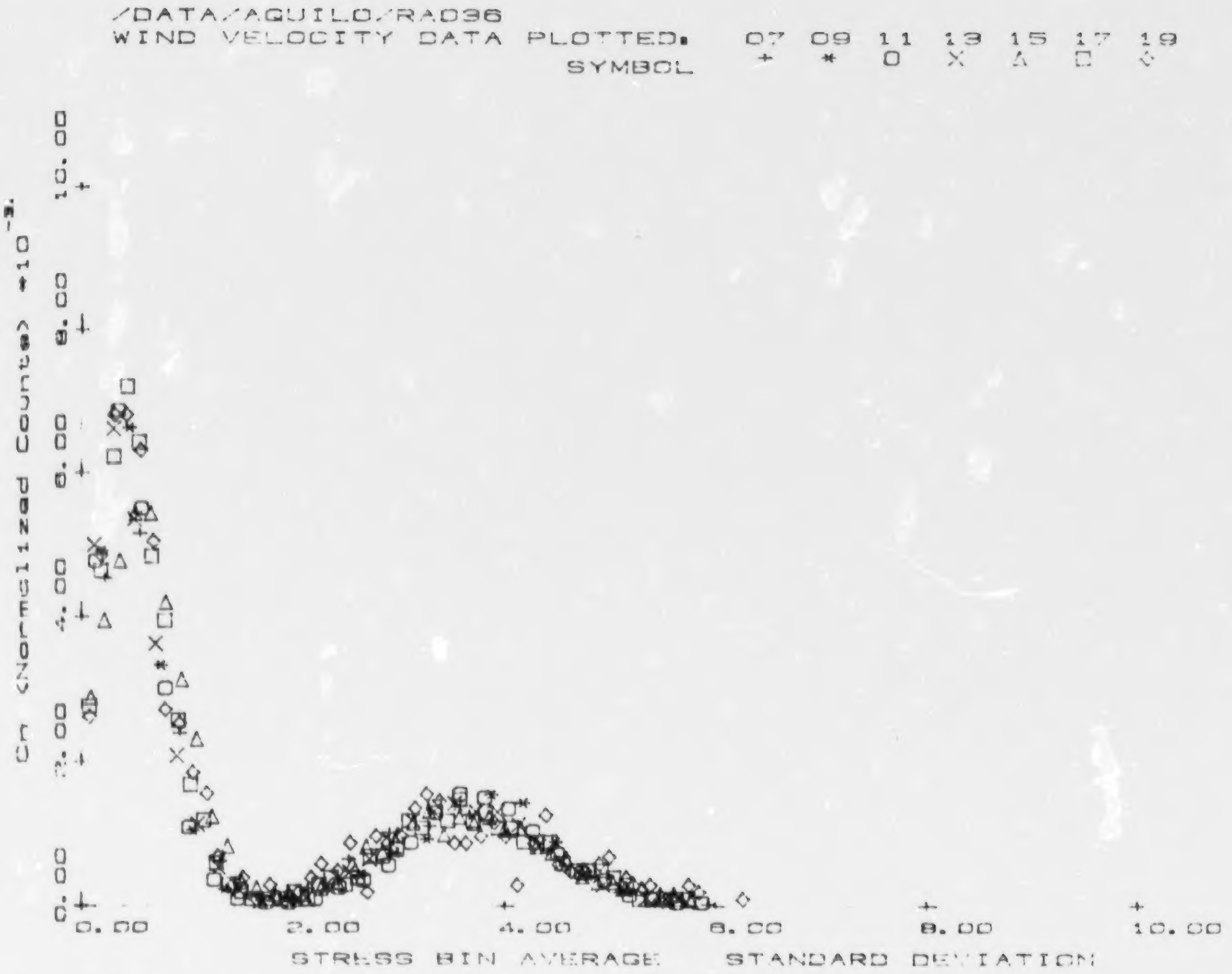


Figure 6: Normalized Rotor Column Rainflow

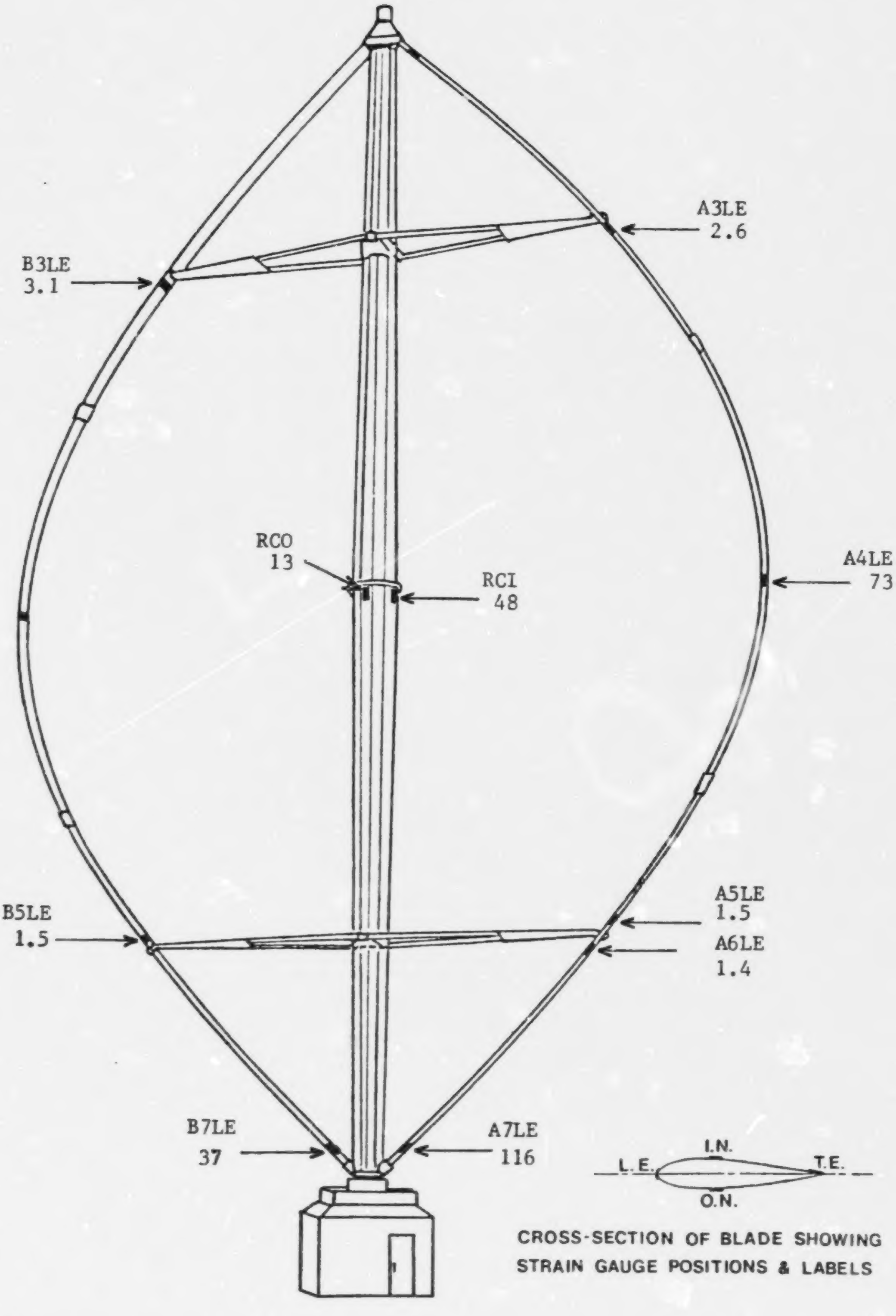

A3LE
2.6
B3LE
3.1
RCO
13
RCI
48
A4LE
73
A5LE
1.5
A6LE
1.4
B5LE
1.5
B7LE
37
A7LE
116
I.N.
L.E.
T.E.
O.N.
CROSS-SECTION OF BLADE SHOWING
STRAIN GAUGE POSITIONS & LABELS

Figure 7: Calculated Life Expectancy for Aquilo Column and Blade Leading Edge Locations (Nov. 1985)

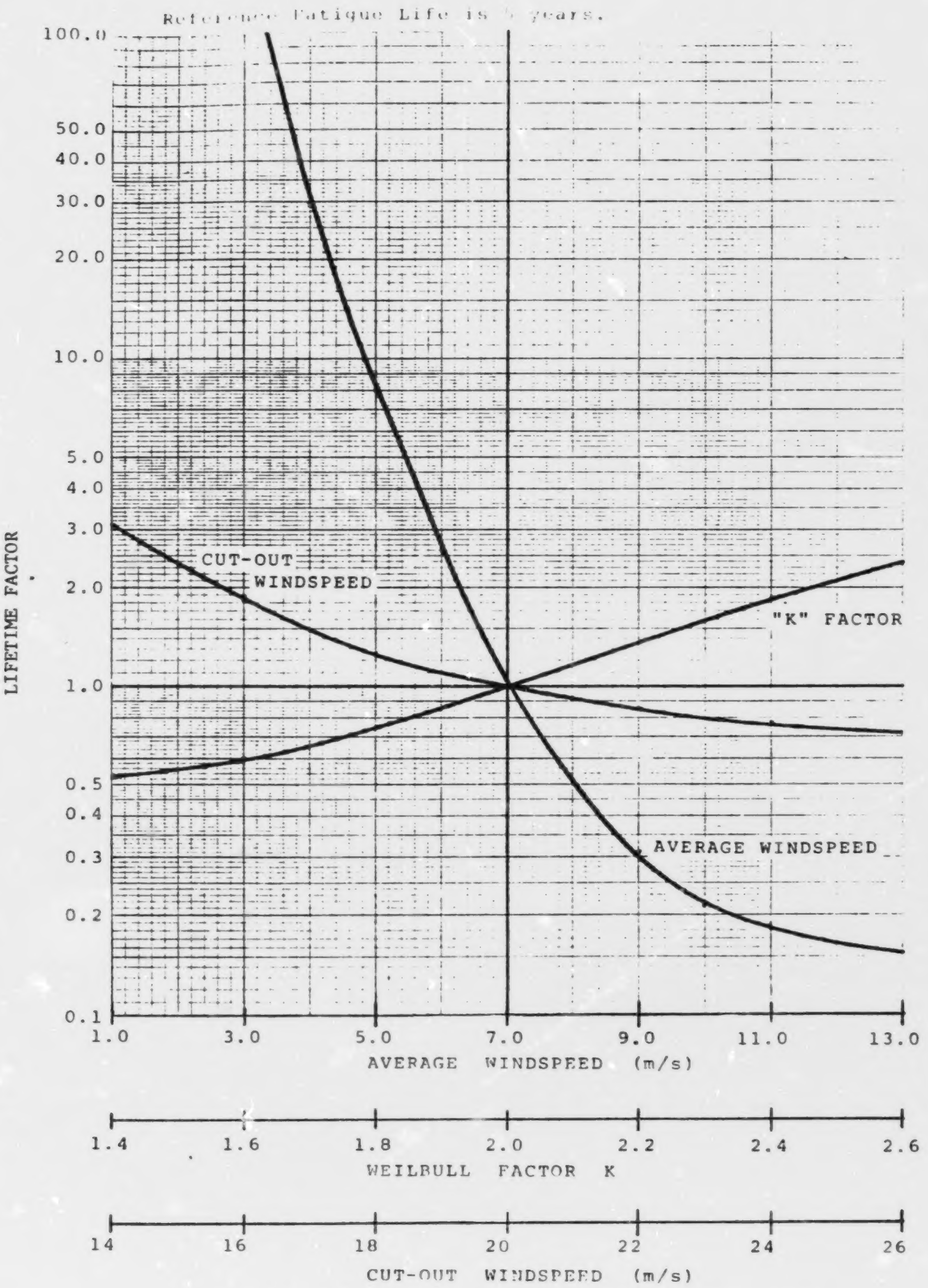


Figure 8: Effects of Wind Regime and Cut-out on Life Expectancy of Blade Leading Edge

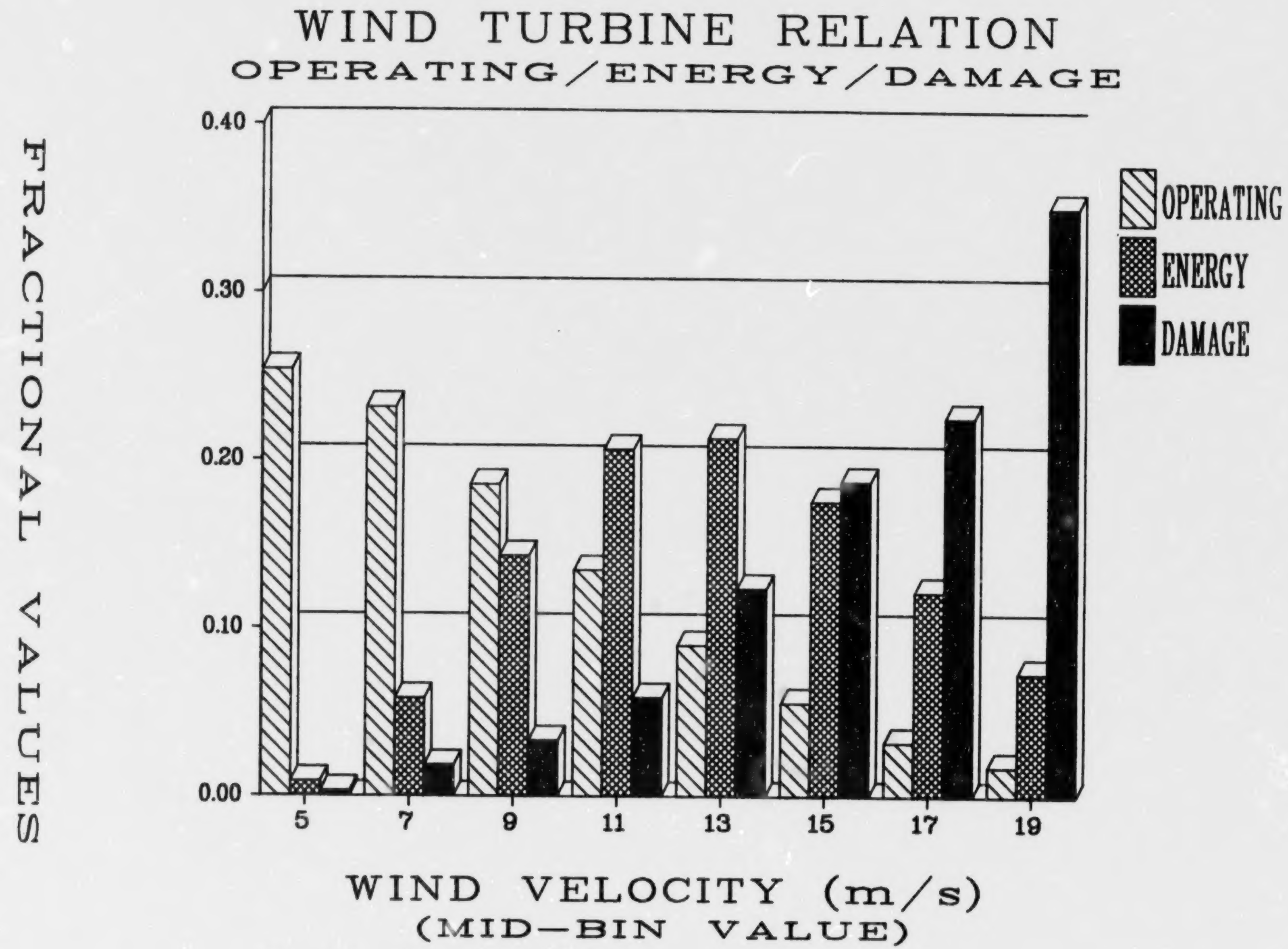


Figure 9: Relationship Between Operating Hours, Energy Output, and Damage for Aquilo
Average Windspeed 7.4 m/s
Weilbull 'k' 1.68

PRELIMINARY INVESTIGATION OF POTENTIAL ICING EFFECTS ON WIND TURBINES

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Arvids Silis
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SUMMARY

A preliminary investigation of the potential effects of icing on wind energy conversion systems (WECS) was undertaken for the Arctic, sub-Arctic and coastal areas of Canada. Specifically, an analysis of freezing rain and potential in-cloud icing was conducted for selected locations in the above geographic regions. Potential wind energy loss was determined during icing events and afterwards if the temperature remained below freezing. It is assumed that ice would remain on a WECS if the air temperatures was less than 0°C. The data used for the anlyses was obtained from the Atmospheric Environment Service's climatic archive.

Mean durations of icing events for all stations ranged from 2 to 4 hours; however, the duration of temperatures less than zero after an event ranged in average from 10 to 20 hours. The analysis of potential energy loss due to icing indicated that up to 10 percent of potential available energy could be affected. Of the 25 locations investigated, ten had potential energy losses of 4 percent or more. These are conservatively low values since meteorological stations are situated in low lying areas and do not provide representative data of the more severe conditions at higher elevations.

1. INTRODUCTION

1.1 General

The more promising geographical regions of Canada for utilization of wind energy conversion systems (WECS) are isolated communities in Arctic, sub-Arctic, and coastal areas. In these parts of the country, the available wind energy can be sufficient to be a potential fuel-saver for diesel generation installations. Little work has been done to investigate what effects atmospheric icing will have on the performance of WECS in these regions. In addition little information exists from which to quantify the effects of ice accumulation on wind turbine performance and behaviour.

Chappel and Templin (1985) have indicated that very little ice accumulation, in the order of 2 or 3 mm, is sufficient to reduce power output significantly. A short freezing rain episode on the 500 kw AQUILO vertical axis wind turbine (VAWT) on Prince Edward Island resulted in a dramatic reduction in power observed (ibid, 1985). A hazardous condition might also occur if an anemometer, controlling a WECS, had its speed decreased while the turbine passed its cutout speed. Anemometer slowdown was also indicated in the above event. This study examined the potential of energy reductions as a result of ice accumulation on a turbine using climatic data.

1.2 Background Information on Atmospheric Icing

Atmospheric ice formation on structures occurs by droplet or particle accretion. Freezing precipitation and in-cloud icing result in the formation of rime or glaze ice. The form of the ice is governed by the temperature of the droplets, their size and the rate at which they strike a surface. Glaze icing occurs predominantly during freezing precipitation and has a density of about 0.9 g/cm^3. Rime deposits occur when structures are exposed in cold fogs or clouds. Ice density in this case is usually in the range of 0.1 to 0.6 g/cm^3.

Freezing rain is most commonly associated with the passage of a warm front. This condition will usually not last more than several hours and is confined to a narrow sweeping band associated with the warm front. The severity and frequency of glaze ice depends on topography, the proximity of moisture sources and the preferred path of storms. Another type of freezing rain know to occur, but far less common, is the case of rain falling through a cold air mass trapped in an enclosed valley. In-cloud icing, resulting from accretion of supercooled fog or cloud droplets, is usually most severe in regions close to large bodies of water, and in coastal ranges.

The actual shape of an ice deposit on a rotor blade is of importance. During glaze icing, drops or droplets do not freeze immediately on impact but run a distance before freezing. The resulting ice deposit shape in this case would likely increase drag. With rime icing, water droplets freeze immediately on impinging on the leading edge of an aerofoil but it is not immediately apparent what effect icing would have. For example, this type of accretion in minor amounts may not necessarily affect the aerodynamic characteristics of the rotor at all; or may, due to an increase in the chord, result in an increase in lift (Mortimer, 1980); or may possibly modify the leading edge geometry sufficiently to disturb the whole flow field which could result in lift decrease and drag increase. Once ice accumulation exceeds some unspecified amount, there will likely be some effect on performance.

Large amounts of glaze or rime ice accretion could be a possible cause of dynamic imbalance as ice chunks are released from the turning rotor. The preliminary standard specified by the Canadian Standards Association (CSA, 1985) stipulates that the design of a small WECS shall consider a minimum ice build-up of 60 mm, with a density of 900 kg/m^3.

1.3 Project Objectives

An analysis of freezing rain and potential in-cloud icing was undertaken for selected locations in the Arctic, sub-Arctic, and coastal areas of Canada in order to investigate potential performance degradation of WECS in these areas. A realistic appraisal of wind energy system downtime due to icing would provide the basis for refined wind resource assessments. The study was undertaken to provide a preliminary evaluation of the significance of icing in the above mentioned locations in Canada.

2.0 METHODS

2.1 Data Source

The primary objective in weather observing station selection was to obtain meteorological data representative of coastal, arctic and sub-arctic regions of Canada. The selected locations are provided in Figure 1. Once this task was completed hourly climatic data for the selected observing stations were obtained from the Atmospheric Environment Service archives for the selected locations. The ten-year period 1967-76 was used in the project since the Atmospheric Environment Service has prepared a wind climatology using the same time interval (Morris and Howell, 1984).

2.2 Data Analyses

Data analyses were conducted, on a microcomputer, under two major categories:

1. icing event occurrence and duration
2. duration of temperatures less than $0^{o}C$ after an event

The number of hours of freezing precipitation (freezing rain and freezing drizzle combined) were compiled for each station along with the frequency of duration of the events. Potential icing due to supercooled fogs or clouds was considered to have occurred when air temperature was less than $0^{o}C$, visibility was less than 1 km, and fog was present.

The visiblity criterion chosen was rather arbitrary due to lack of definitive relations between visibility and liquid water content. For inland radiation fog, a visibility of 1 km may be associated with a liquid water content of about .01 g/m^3 (i.e. Pinnick et al. 1978) whereas the corresponding liquid water content for coastal advection fog may be in the order of .04 g/m^3 (Kumai, 1973). The liquid water content (LWC) in the air is of great importance to the amount of ice accreted.

The amount of water captured by a unit length of a blade per unit time can be written as (after Gustafsson et al., 1982)

$$Wm = LWC \times h \times F \times V$$

where Wm = mass of captured water
h = thickness of blade measured perpendicular to V
F = efficiency of catch (collection efficiency) i.e. ratio of water captured to water in the air
V = blade velocity

Collection efficiencies calculated by Langmuir and Blodgett (1946) show that F increases rapidly as drop radius and wind speed increase. As the blade thickness increases the efficiency decreases. Considering a hypothetical blade thickness of.05 m, a collection efficiency of 0.5, a blade velocity of 25 m/s, and a liquid water content of 0.01 g/m^3, results in 0.006 g/sec being deposited over a 1 metre blade length. In a one-hour period, this would accumulate to about 22.5 grams or a thickness of about 1 mm if the accumulated ice density is in the vicinity of 600 kg/m^3. A one millimetre thickness might be considered as possibly affecting WECS performance in light of the observations of Chappell and Temlin (1985) referred to in Section 1.1.

Occurrence and duration statistics were compiled by the month and for the total period of record. For monthly values, an event begun in one month and ending in another was assigned to the month in which it began.

For each icing event defined in the preceding methodology, the length of time, in hours, for which the temperature remained below zero after icing was determined. This duration and the icing duration provide the total amount of time that a wind energy turbine might be affected by icing. The potential wind energy density lost during these periods was calculated on an hourly basis according to (Morris and Howell, 1984):

$$P_d = 0.037355\ PV^3/(T + 273.15)$$

$$E = P_d\ S \times 10^{-6}$$

where

P_d is the wind power density (Wm^{-2})
P is the atmospheric pressure (kPa)
V is the wind speed (kmh^{-1})
T is air temperature (^{o}C)
E is the wind energy density (MJm^{-2})
S is the duration of the period (seconds)

The parameters P, V, and T were obtained directly from the hourly AES climatic records and used to calculate wind energy density. These equations account for the rate at which kinetic energy in the wind stream is delivered perpendicular to a unit area. The actual amount of energy that can be extracted from the wind stream depends on the wind speed distribution and the characteristics of the WECS. The relations do provide a method of characterizing the available wind power (or as in the present case wind energy lost due to icing) of various sites. The wind speeds obtained from AES although nominally one-minute mean speeds observed on the hour are used as one-hour mean values in the above relation.

Potential average annual wind energy lost due to icing was compared with potential available average annual wind energy values provided by the Atmospheric Environment Service (R. Morris, pers. comm.). The Atmospheric Environment Service wind energy data were adjusted to a standard 10-metre height above ground. Hence, the comparisons need to be qualified for stations, used in the present analyses, where wind speeds are measured at higher elevations. In this case, the wind energy potential lost due to icing relative to the total available would be lower than the analyses indicate; however, only a relatively few stations are affected and usually for only short periods as indicated below:

Frobisher Bay	13.1 m from beginning to 09/68
St. John's	19.8 m from beginning to 07/69
Sept-Iles	18.6 m from beginning to 09/67
Swift Current	13.1 m from beginning to 02/70
Thompson	13.1 m for entire 10-year period

3.0 DATA ANALYSES RESULTS

3.1 Icing Event Occurrence and Duration

Freezing Precipitation

The annual characteristics of the freezing precipitation events at the various locations are provided in Table 1. The mean duration of freezing precipitation events for all stations range only from 2 to 4 hours; however the duration of temperatures less than zero after an event range from 3 hours at Port Hardy to 24 hours at Kuujjuarapik. Gander had the largest number of freezing precipitation events over the ten year period (352) and the largest number of hours of freezing precipitation (1343) while the least was recorded at Port Hardy (4 events for a total of 14 hours). The distribution frequency of events and hours over the ten-year analysis period is provided below:

NUMBER OF EVENTS

0-50	51-100	101-200	201-300	301-400
6	6	12	1	2

NUMBER OF HOURS

0-200	201-600	601-1000	1000-1400
12	12	1	2

After freezing precipitation events, the potential residence time of ice (as indicated by air temperatures below $0^{o}C$) varied greatly among stations. The percentage of freezing precipitation events followed by freezing temperature periods varied from 25 % at Port Hardy to 83 % at Cambridge Bay. The largest number of post events occurred at Cape Parry (202) and the largest number of hours was also recorded at this location (4728). The distribution frequency of post events and hours for the selected locations is given in the following:

NUMBER OF EVENTS

0-50	51-100	101-200	201-300	301-400
8	12	5	1	0

NUMBER OF HOURS

0-200	201-600	601-1000	1001-1400	>1400
3	5	3	6	9

The total number of hours in a ten-year period is 87603. Over 6 percent of the time, freezing precipitation or ice may be present at Gander or Cape Parry. At 4 percent, the location list can be increased to include St. John's. Only the locations in British Columbia and Burwash in the Yukon have occurrence levels less than 1/2 percent.

The monthly occurrences of freezing precipitation vary with geographic location. For the sub-Arctic locations, such as Yellowknife and Nitchequon, the greatest frequency of events occurs during November and December. In the Arctic, the frequency of occurrence is bimodal with the greatest frequencies occurring during April or May and October or November. The pattern in the Maritimes has peak occurrence during the months January through March. At all stations, with the exception of Cape Parry there were no or rare occurrences (1 or 2) of freezing precipitation during July or August.

Supercooled Fog

The annual characteristics of supercooled fog events and post events (air temperature less than $0^{o}C$) are provided in Table 2. The mean duration of events is confined to a narrow range of 2 to 3 hours with the exception of Port Hardy which has a one hour mean duration. The mean duration of temperatures less than zero after an event ranges from 6 hours at Prince Rupert, Abbotsford, and Burwash to 114 hours at Thompson. St. John's had the largest number of events of supercooled fog over the ten year period (247) and the largest number of supercooled fog hours (788). Port Hardy has the least number of events (4) and hours of occurrence (4). The distribution frequency of events and hours of occurrence over the ten-year period is provided in the following (the intervals used for freezing precipitation have been retained for supercooled fog):

NUMBER OF EVENTS

0-50	51-100	101-200	201-300	301-400
13	4	8	1	0

NUMBER OF HOURS

0-200	201-600	601-1000	1000-1400
16	9	1	0

After a supercooled fog event, temperatures are more likely to remain below freezing than for a freezing precipitation event. The percentage of supercooled fog events followed by freezing temperatures varies from 50 percent at Port Hardy to 100 percent at Cambridge Bay. The largest number of post events occurred at St. John's (157) and the largest number of hours was observed at Cape Parry (1987). The distribution frequency of event occurrence and hours for the stations in Table 2 is provided below:

NUMBER OF EVENTS

0-50	51-100	101-200	201-300	301-400
13	5	8	0	0

NUMBER OF HOURS

0-200	201-600	601-1000	1001-1400	>1400
3	7	5	3	8

St. John's, Gander, Grindstone Island, Hall Beach, Cape Parry, Cambridge Bay, and Smithers have more than 2 percent occurrence of supercooled fog and potential ice presence. No stations exceed 4 percent compared with 3 stations for freezing precipitation. Daniels Harbour, Cartwright, Burwash, Nitchequon, Big Trout Lake, Prince Rupert, Abbotsford, and Port Hardy have less than 0.5 percent level of occurrence.

The monthly variation of supercooled fog occurrence is similar to that of freezing precipitation (refer to Section 3.1.1).

3.2 Potential Wind Energy Loss

Potential wind energy lost during and following icing events in periods of freezing temperatures are provided in Table 3. The potential average annual wind energy density available at these sites are provided for comparison. In all cases, the largest potential loss of energy occurs from ice residence after an icing event. For example, at Gander, 314 MJ/m^2 of annual average energy may be lost after freezing precipitation events compared with 147 MJ/m^2 during an event. At the same location, potential energy lost from supercooled fog icing is 18 MJ/m^2 compared with 195 MJ/m^2 after events from ice adherence.

The largest amount of potential energy lost, 1323 MJ/m^2 occurred at Grindstone Is. which represented 5.1% of the total available energy at this site. There is no overall trend by region for the percentage of potential energy lost by icing causes. For example in the Maritimes, power lost varies from as little as 1.3 percent at Daniels Harbour to 10.2 percent at Gander. Similarly, in the Arctic, lost power ranges from 0.1 percent at Burwash to 8.4 percent at Cape Parry. Overall, power loss in British Columbia is small but so is the potential available energy at these four locations.

The seasonal variation of potential wind energy loss from freezing precipitation and supercooled fog events are provided in Tables 4 and 5, respectively. Both freezing precipitation and fog follow the same monthly pattern and tend to peak together. Maximum monthly potential energy possibly affected by ice is in the vicinity of 30 percent during peak icing season.

4.0 DISCUSSION OF RESULTS

4.1 Potential Wind Energy Loss

This preliminary investigation of potential power loss due to icing has indicated that up to 10 percent of potential available energy could be affected by icing. Of the 25 locations investigated, ten had potential power losses of 4 percent or more. This is however a conservatively low figure for a number of reasons:

observations are from locations not representative of higher altitudes
weather observations are only representative of the near surface layer of 10 m above ground level
measured wind data may not be accurate due to icing of the anemometer

Altitude Effects

With regard to the first point, areas with the highest icing potential are not well represented by weather observing stations in the Atmospheric Environment Service network. Even where an observing station is close to an area of interest, topographical effects can greatly modify ice accretion severity over small distances.

There are locations, where icing is so severe and residence time so long that installation of a WECS would not be practical. Extremely heavy icing can be expected at higher elevations along the St. Lawrence Valley and along the coasts. The following paragraphs provide some examples to indicate the potential impracticality and problems of locating WECS at high elevations in certain regions of the country.

Observations at Mont Sutton in Quebec provide an indication of the frequency that higher elevations may be immersed in cloud (Schemenauer, 1986). For example during January 1986, the summit of Mont Sutton (elevation 970 m) was in cloud 65 percent of the time at 0800 EST and 48 percent during the period from 1200 to sunset. Under these conditions, a rime ice deposit could conceivably grow as well as persist throughout the month.

Felin (1976) provides some examples of damaging ice events in Quebec caused by locating transmission lines in exposed and elevated areas. In November 1969, twenty-nine towers on Mont Elie, collapsed due to ice loads. The site of the accident was approximately 900 metres above sea level and the first mountain to intercept the humid air coming from the Gulf of St. Lawrence. The response to the accident was to reconstruct the line to pass at the foot of Mont Elie.

Variation of Meteorological Parameters Above the Surface

The variation of icing with height at one site can be illustrated with observations made in Sweden by Gustafsson et al. (1982). During a winter period of two months 9-hours of icing were detected at the 10-m level and 76 hours were detected at the 75-m level. For inland fogs, one would also expect a substantial increase of liquid water content with height above ground (i.e Pinnick et al., 1978).

Accumulation of rime ice would also vary with WECS height due to the increase in wind speed with height. Thus for large WECS installations one would expect both an increased incidence of icing and more severe icing than obtained from surface meteorological information in areas prone to in-cloud icing.

Anemometer Icing

Finally, icing of anemometers may cause a decrease in observed windspeed which would translate into a smaller indication of potential wind energy lost than actually occurs. This will also be included in the total potential available wind energy but will be of greater importance for just the icing conditions.

Seasonal Aspects of Potential Wind Energy Loss Due to Icing

An additional consideration is the seasonality of potential wind energy loss due to icing. At most locations, more than 50 % of the potential power loss from icing occurs in two months. Up to 20 percent of the time could be affected by ice in these months. In other words, WECS power loss or reduction could be dramatic in the peak icing months at the locations most susceptible to icing.

4.2 Ice Residence Time

The length of time that ice remains on a WECS after an icing event is important, since it directly affects the potential downtime and the probability of encountering a high wind speed. There are very few observations of residence times of ice. Extreme durations of icing noted in the literature include 8 days for glaze ice in Iowa (Bennett, 1955) and six weeks for ice that formed during a storm in the Upper Connecticut Valley of the United States (Bendell and Paton, 1981).

Duration of ice is highly dependent on local temperatures and geographical location. In this study the maximum duration was limited to 10 days due to computing restrictions. There were two locations where the maximum was encountered. Fort Chimo had 10 240-hr periods after freezing precipitation and 13 after supercooled fog while one 240-hr period after supercooled fog was recorded for Cape Parry. It was at first, somewhat surprising to encounter so few occurrences of below freezing periods of 10 days or longer considering the observations in the United States. However, icing occurs frequently only in seasons where the temperature is in the vicinity of 0°C and thus there is some opportunity for the temperature to climb above zero in a relatively short time period even for Arctic stations.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Analyses of climatological data pertaining to icing has indicated possible difficulties in operating WECS in certain areas of Canada. These areas include parts of the Maritimes, and the Arctic coastal regions. The major concern is the loss or reduction of power due to substantial residence time of accreted ice. While the mean duration of a freezing precipitation event is 2 to 3 hours, the temperature often remains below zero after the event for mean durations usually in the range of 10 to 20 hours. A similar situation exists for supercooled fog.

The results are not indicative of the conditions to be found at elevations higher than the selected weather station locations where a much higher frequency of occurrence and persistence of icing would be expected.

5.2 Recommendations

The recommendations of this study are directed towards WECS operation and to furthur investigations. The results of this pilot study indicate that there is the potential for wind energy to be severely limited during icing seasons in some areas of Canada. In locating a wind turbine, careful consideration should be given to the icing conditions in the region and the seasonal variation of these conditions. This study has investigated only a limited number of stations and has revealed potential problem areas. An obvious extension of this project is the analysis of upper air data for meteorological stations in ice-prone regions of the country. This would provide a first quantitative estimate of the increased frequency and persistence of icing with altitude.

Furthur investigations could be conducted but obtaining actual ice accretion information from an operating wind turbine is preferable. In this study, certain assumptions have been made regarding how much icing would affect WECS performance. There is a need to obtain quantitative data if icing degradation is to be accounted for in providing WECS designs for isolated or elevated areas. Cooperation with research conducted by the electrical utilities could be beneficial in delineating icing problems with respect to WECS.

In point form, recommendations stemming from this study are:

(i) to extend this analysis to upper air stations in selected regions of Canada to provide an indication of the altitude hazard of icing

(ii) to collect data on a WECS in an ice prone area

(iii) to develop a methodology (i.e. icing model) where the performance degradation of a WECS can be incorporated in a wind resource assessment

ACKNOWLEDGEMENT

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TABLE 1

FREEZING PRECIPITATION

	EVENT			POST EVENT			
	Mean Duration (hr)	No. of Events	Total No. of Hours	Mean Duration (hr)	No. of Events	Percent*	Total No. of Hours
St. John's	4	335	1310	17	162	48.4	2817
Gander	4	352	1343	17	196	55.7	3396
Daniels Harbour	2	106	243	16	46	43.4	755
Stephenville	2	101	199	11	46	45.5	495
Sydney	3	193	637	15	79	40.9	1149
Yarmouth	3	76	215	16	39	51.3	607
Chatam	3	163	514	10	91	55.8	930
Summerside	2	186	409	11	108	58.1	1212
Grindstone	2	187	457	11	94	50.3	1021
Sept Iles	3	104	341	9	64	61.5	562
Kuujjuarapik	2	100	183	24	64	64.0	1514
Yellowknife	4	126	452	21	86	68.3	1801
Baker Lake	2	81	195	15	60	74.1	895
Hall Beach	2	75	142	21	61	43.0	1258
Cape Parry	2	271	579	23	202	74.5	4728
Cambridge Bay	3	138	354	20	115	83.3	2310
Frobisher Bay	2	31	72	20	22	71.0	444
Burwash	2	13	27	30	7	53.8	211
Thompson	3	140	365	14	99	70.7	1399
Nitchequon	2	84	175	22	54	64.3	1191
Big Trout Lake	2	123	266	19	95	77.2	1807
Smithers	2	25	59	20	20	80.0	403
Prince Rupert	3	10	27	9	6	60.0	56
Abbotsford	4	41	158	4	22	53.7	85
Port Hardy	4	4	14	3	1	25.0	3

* percent of icing events that were followed by a period where air temperatures were < 0°C.

TABLE 2

SUPERCOOLED FOG

	EVENT			POST EVENT			
	Mean Duration (hr)	No. of Events	Total No. of Hours	Mean Duration (hr)	No. of Events	Percent*	Total No. of Hours
St. John's	3	247	788	11	157	63.6	1788
Gander	2	135	310	14	109	80.7	1501
Daniels Harbour	2	24	42	15	21	87.5	324
Stephenville	2	21	43	15	20	95.2	300
Sydney	3	110	282	11	103	93.6	1105
Yarmouth	2	43	204	19	37	74.4	615
Chatam	2	49	110	10	44	89.8	422
Summerside	2	51	90	16	51	100.0	830
Grindstone	3	108	286	20	96	88.9	1900
Sept Iles	2	209	244	12	108	99.1	1300
Kuujjuarapik	2	91	200	17	80	87.9	1350
Yellowknife	3	90	258	18	78	86.7	1441
Baker Lake	3	50	137	16	47	94.0	772
Hall Beach	3	141	403	13	122	86.5	1578
Cape Parry	3	176	532	13	152	86.4	1998
Cambridge Bay	3	117	329	17	113	100.0	1967
Frobisher Bay	2	33	82	15	31	99.0	477
Burwash	3	18	52	6	13	72.2	73
Thompson	2	47	109	114	42	89.4	604
Nitchequon	2	33	78	12	26	78.8	304
Big Trout Lake	2	22	51	12	22	100.0	261
Smithers	3	160	429	11	158	98.8	1724
Prince Rupert	2	33	51	6	28	84.8	167
Abbotsford	2	47	96	6	40	85.1	231
Port Hardy	1	4	4	25	2	50.0	50

* percent of icing events that were followed by a period where air temperatures were < 0°C.

TABLE 3

ANNUAL AVERAGE WIND ENERGY (MJ/m^2)

	During Freezing	Post Precipitation	During Supercooled	Post Fog	Total	Potential All Hours	% Lost
St. John's	221	494	58	250	1023	10872	9.4
Gander	147	314	18	195	674	6605	10.2
Daniels Harbour	63	95	2	44	204	15584	1.3
Stephenville	25	50	1	15	91	6019	1.5
Sydney	72	116	12	140	340	6889	4.9
Yarmouth	31	52	3	91	177	5806	3.0
Chatam	11	36	1	21	69	2613	2.6
Summerside	51	154	2	85	292	6661	4.4
Grindstone	208	457	16	642	1323	26066	5.1
Sept-Iles	34	54	20	155	263	4289	6.1
Kuujjuarapik	15	110	8	96	229	5418	4.2
Yellowknife	10	65	2	40	117	3037	3.9
Baker Lake	29	131	11	67	238	11622	2.0
Hall Beach	16	177	17	294	504	11142	4.5
Cape Parry	34	460	33	105	632	7507	8.4
Cambridge Bay	42	377	25	336	780	12388	6.3
Frobisher Bay	5	21	1	25	52	4387	1.2
Burwash	1	1	<1	<1	2	2927	0.1
Thompson	10	36	2	17	65	2060	3.2
Nitchequon	12	53	1	8	74	3816	1.9
Big Trout Lake	13	84	1	7	105	3082	3.4
Smithers	<1	1	<1	4	5	726	0.6
Prince Rupert	<1	3	1	2	6	4188	0.1
Abbotsford	3	1	<1	1	5	2115	0.2
Port Hardy	7	5	1	8	21	3416	0.6

TABLE 4
POTENTIAL WIND ENERGY LOST BY MONTH DURING AND AFTER FREEZING PRECIPITATION EVENTS

Location	Percent of Monthly Average Wind Energy Density											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
St. John's	15	6	13	16	6	0	0	0	0	*	1	8
Gander	14	9	10	15	3	0	0	0	0	2	5	8
Daniels Harbour	3	2	1	1	*	0	0	0	0	*	*	2
Stephenville	3	2	2	1	0	0	0	0	0	0	*	2
Sydney	6	4	8	5	*	0	0	0	0	0	*	2
Yarmouth	1	4	3	*	0	0	0	0	0	0	0	3
Chatam	3	2	2	1	0	0	0	0	0	0	7	3
Summerside	9	4	5	1	0	0	0	0	0	0	*	8
Grindstone	4	3	7	2	*	0	0	0	0	0	*	6
Sept-Iles	4	1	2	9	*	0	0	0	0	*	1	3
Kuujjuarapik	4	1	1	5	7	1	0	0	*	*	7	1
Yellowknife	*	1	2	1	3	0	0	0	0	10	11	2
Baker Lake	0	0	0	*	5	3	0	0	*	5	4	*
Hall Beach	0	0	0	*	2	2	*	0	5	6	1	*
Cape Parry	1	*	*	*	21	3	*	3	16	26	1	1
Cambridge Bay	0	0	0	2	7	7	0	0	6	13	2	0
Frobisher Bay	0	0	0	*	1	*	0	0	0	5	1	0
Burwash	0	0	0	0	0	0	0	*	*	*	*	*
Thompson	2	1	1	3	1	*	0	0	*	2	14	9
Nitchequon	1	*	2	2	*	0	0	0	0	7	5	1
Big Trout Lake	1	*	3	3	3	0	0	0	*	2	19	3
Smithers	*	*	0	0	0	0	0	0	0	0	*	1
Prince Rupert	*	0	0	0	0	0	0	0	0	0	*	*
Abbotsford	1	*	0	0	0	0	0	0	0	0	*	*
Port Hardy	2	0	0	0	0	0	0	0	0	0	0	*

* indicates less than 0.5 %

TABLE 5
POTENTIAL WIND ENERGY LOST BY MONTH DURING AND AFTER SUPERCOOLED FOG EVENTS

Location	Percent of Monthly Average Wind Energy Density											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
St. John's	3	8	7	4	*	*	0	0	0	0	*	5
Gander	5	3	7	9	*	*	0	0	0	3	1	3
Daniels Harbour	*	1	1	2	*	0	0	0	0	0	0	*
Stephenville	*	*	1	2	0	0	0	0	0	0	0	0
Sydney	5	1	5	5	3	0	0	0	0	0	0	3
Yarmouth	2	3	4	*	*	0	0	0	0	0	0	3
Chatam	*	2	1	1	*	0	0	0	*	*	5	*
Summerside	1	3	5	4	0	0	0	0	0	0	0	*
Grindstone	3	3	9	13	*	0	0	0	0	0	0	*
Sept-Iles	4	2	4	10	1	0	0	0	0	*	3	9
Kuujjuarapik	0	0	1	5	4	*	*	0	0	*	6	4
Yellowknife	0	*	1	*	*	0	0	0	0	6	6	2
Baker Lake	0	0	0	*	4	0	0	0	0	5	*	*
Hall Beach	0	0	0	0	5	2	*	*	6	12	*	*
Cape Parry	0	0	*	1	8	3	*	2	1	5	1	0
Cambridge Bay	0	0	0	*	8	12	0	0	7	5	1	0
Frobisher Bay	0	*	0	0	5	*	*	0	0	1	*	*
Burwash	0	1	0	*	*	0	0	*	0	*	*	0
Thompson	0	*	1	*	1	*	0	0	*	4	4	3
Nitchequon	0	0	*	1	*	*	0	0	0	*	1	*
Big Trout Lake	0	0	*	*	*	0	0	0	*	*	1	*
Smithers	*	1	*	0	0	0	0	0	*	*	2	3
Prince Rupert	*	*	*	0	0	0	0	0	0	*	*	*
Abbotsford	*	*	*	0	0	0	0	0	0	*	*	*
Port Hardy	*	*	0	0	0	0	0	0	0	0	2	0

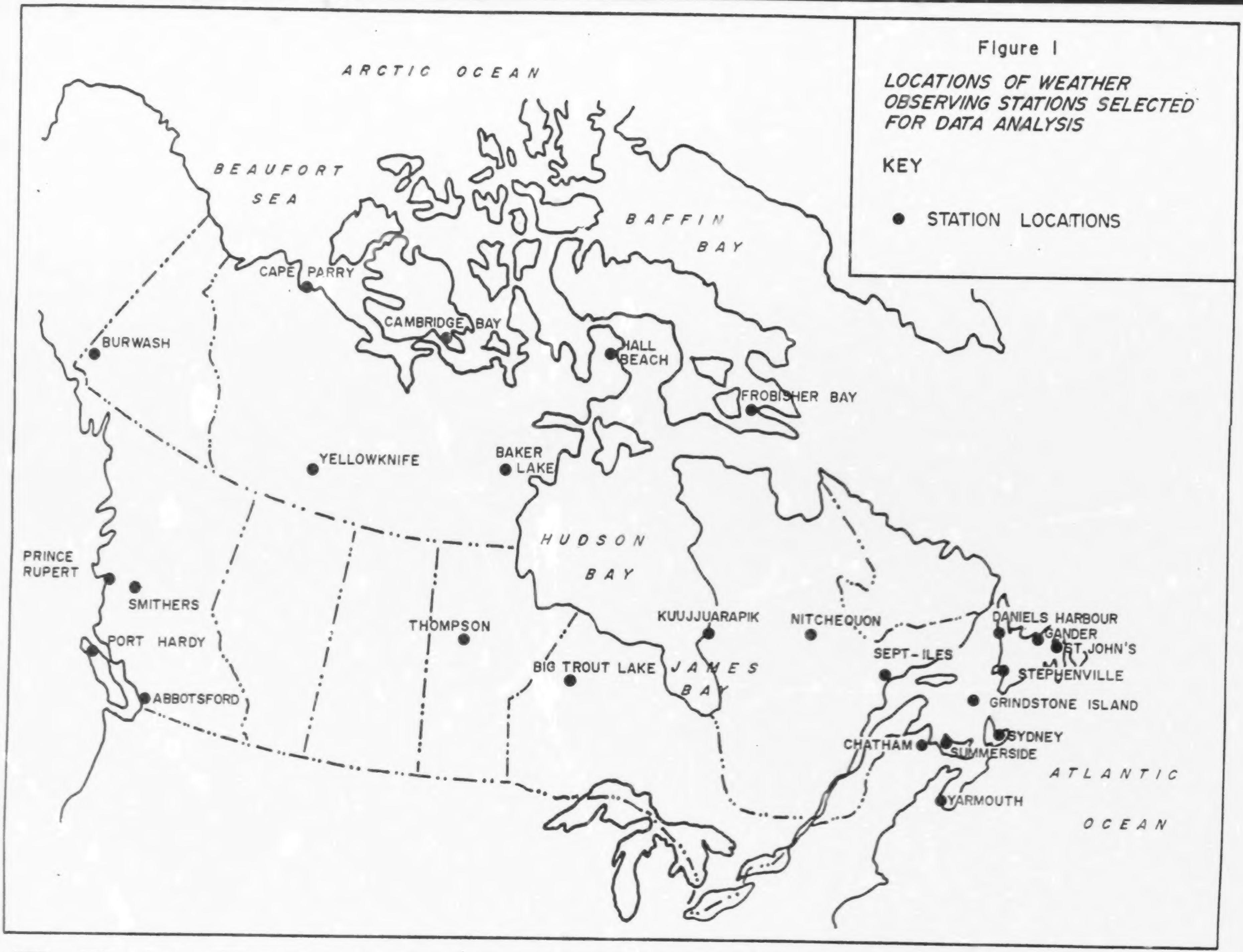


Figure I

LOCATIONS OF WEATHER OBSERVING STATIONS SELECTED FOR DATA ANALYSIS

KEY

● STATION LOCATIONS

ARCTIC OCEAN
BEAUFORT SEA
BAFFIN BAY
HUDSON BAY
JAMES BAY
ATLANTIC OCEAN
CAPE PARRY
CAMBRIDGE BAY
HALL BEACH
FROBISHER BAY
BURWASH
YELLOWKNIFE
BAKER LAKE
PRINCE RUPERT
SMITHERS
PORT HARDY
ABBOTSFORD
THOMPSON
BIG TROUT LAKE
KUUJJUARAPIK
NITCHEQUON
SEPT-ILES
DANIELS HARBOUR
GANDER
ST JOHN'S
STEPHENVILLE
GRINDSTONE ISLAND
SYDNEY
CHATHAM
SUMMERSIDE
YARMOUTH

DEVELOPMENTS IN SINGLE-BLADED ROTORS

Colin C. Kerr
Thermax Energy Corporation Limited
39 Main Street
Vankleek Hill, Ontario KOB 1RO

SUMMARY OF CHARACTERISTICS -

1. Balance - No problem, with counterweight.
2. RPM - Relatively high.
3. Weight - Low.
4. Dynamics - Major advantages, rotor decoupled from tower.
5. Cyclic Speed Variation - Disadvantage.
6. Solidity - Relatively low.
7. Noise - Noticeable but low.
8. Aesthetics - No love at first site, but good at operating speed.
9. Economics - Cost-effective, long-lasting.

Since the mid-1980s, the single-bladed wind generator has received considerable attention in the continuing search for more durable, cost-effective wind energy converters.

A number of well-established manufacturers, including Messerschmitt-Bolkow-Blohm of West Germany and Riva Calzoni of Italy, have recently developed commercial single-bladed wind generators ranging from 5 to 1,000 Kw rating.

The principal characteristics, advantages and disadvantages of single-bladed rotors are:

1. Counterweight for Mass Balance -

The single blade requires a counterweight for balanced rotation. The counterweight, located near the center of rotation, with low angular velocity and drag, can be streamlined to further minimize drag. Initial and periodic fine adjustment of balance is easily achieved.

2. Higher RPM

The rpm of a single-bladed rotor is relatively higher for the same wind and load conditions than that of multiblade rotors, which results in lower torque. Consequently, (a) the generator gearing-up ratio can be smaller and (b) the main shaft can be lighter.

A secondary advantage of a higher operating rpm is that the natural resonant frequencies of the tower structure will be correspondingly further removed from the vibrations induced into the tower by the rotor, during power production. Tower/rotor dynamics are therefore somewhat improved.

3. **Weight -**

The weight of the active rotor blade is half, or less, that of a multiblade rotor. The cost of manufacturing the blade is correspondingly reduced, as are other weight-related factors such as shipping, erection cost and the risk of blade damage or failure.

4. **Dynamics -**

The single-bladed rotor offers a very distinct dynamic advantage - it is "softer" than most other rotor types because it inherently possesses an additional degree of freedom, that is, the blade can be articulated at the root to flap freely (from front to back), of course between two damped limiting bumpers.

In operation, the radial component of the two vector components of the aerodynamic lift of the rotor airfoil turns the rotor and the shaft - and ultimately the generator - and the axial component pushes the blade backwards. In a regular rigid rotor system, the result is a backward bending moment against the whole structure-wind generator and tower, all forces being applied through the blade roots, which is one reason why stresses and fatigue in blade roots and fastenings are so critical in multiblade machines. In the freely hinged single-bladed rotor, at startup, the blade is pushed back against its rear bumper. But the energy in the wind at startup is not great, so the net bending moment passed to the shaft and tower at this point is low.

After startup, the rotating blade becomes increasingly subject to centrifugal force, which tends to pull it straight outwards towards perpendicularity to the shaft. So an equilibrium blade position is established, which changes with windspeed and load, but which almost never applies any significant bending forces to the shaft.

The effect of this dynamic balance is to effectively decouple the rotor from the tower.

5. **Cyclic Variation of Angular Velocity -**

This is a particular disadvantage of the single-bladed rotor, shared, with a few other rotor types such as Darrieus and Savonius.

As the single-bladed rotor goes through the upper half of its rotation, it rotates slightly faster than when in the lower half, due both to the variation of wind speed with height above ground, and, in the case of a downwind rotor such as the MBB MON15, to the turbulence of tower wake in the lower half revolution.

This is a problem for synchronous generation - which will disappear as soon as a true variable-speed synchronous generator has been produced.

Of course, the same phenomenon is happening in multiblade rotors, but since the blades are all fixed tightly together, the individual blade speed variations end up as powerful dynamic stresses in the root and hub area, ultimately leading to component fatigue.

6. Solidity -

Less blade area of course means lower disc solidity. This has an effect on transient operation but, according to current engineering analysis, still follows the established rules of rotor dynamics.

7. Noise -

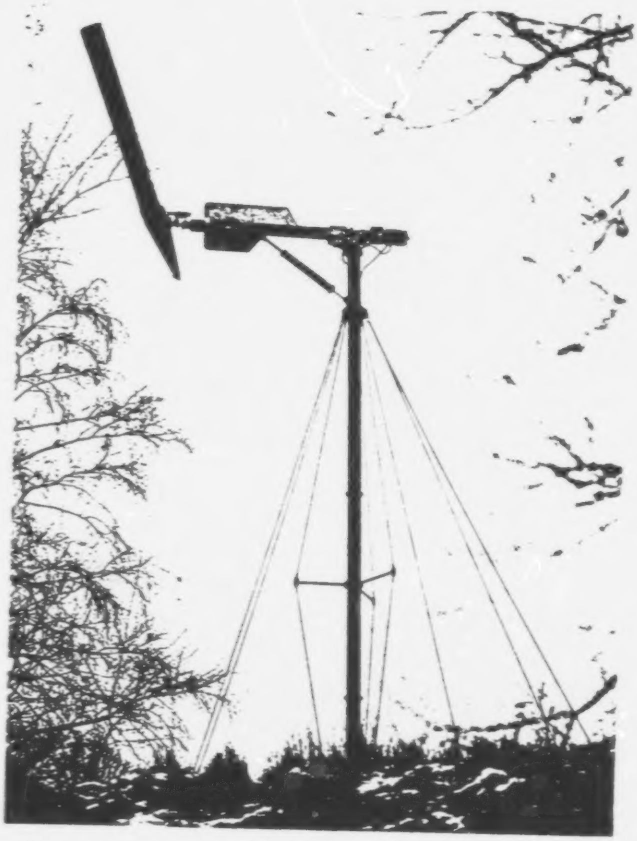
The single-bladed rotor produces an audible swish once per revolution. The revolutions are relatively faster than multiblade rotors, but the fact that the swishes are separated by silences makes the sound more noticeable even though it is not actually any louder. In fact the total energy dissipated as noise is less, due to having only one blade to generate the noise. The sound of a small single-bladed rotor has been compared to the sound of a panting dog.

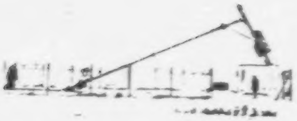
8. Aesthetics -

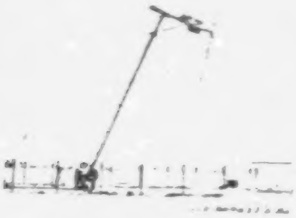
A very common first impression of a single-bladed wind generator is that it might fly apart when it gets going, or, that it could wobble uncontrollably. It is perfectly normal human conditioning to think that anything which is large and rotates ought to look visually balanced.

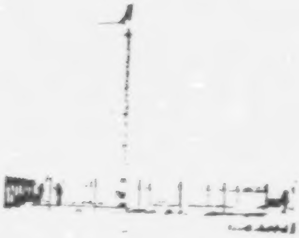
This aesthetic problem only exists when the machine is stationary - once it is rotating reasonably fast the visual unbalance disappears.

TYPE	MON 15
Rated output (kW)	30
Wind speed cut-in/cut-out (m/s)	4.5/18
rated/design max (m/s)	10/54
Hub height (m)	—
No. of machines in operation	15
ROTOR	
No. of blades	1
Diameter (m)	15-17
Speed of rated output (rev/min)	112
Max speed (rev/min)	134
Overspeed protection type	Pitch/brake
Upwind/downwind	Downwind
Type of hub	Teeter
Method of control	Hydraulic
Cone angle	Free coning
Tilt angle	0
Teeter angle	25
Weight excluding blades (t)	0.25
Yaw type	Free
BLADE	
Length of single blade (m)	7.5-8.5
Material/construction	GRP
Weight per blade (t)	0.08
Aerofoil	FX84-W140
Twist	15°
Tip speed ratio at max coefficient of performance	11 at Cp = 0.39
Blade chord	Max 0.76
Pitch	45°
Pitch control	Electronic/hyd
TOWER	
Type	Guyed
Material	Steel
Diameter of base/top (m)	0.6/0.3
Weight (t)	1.2
Gear manufacturer	Flender
Gear type	Spur
Gear ratio overall	13.58
Generator manufacturer	Hademann
Type	Induction
Rating (kW/kVA)	30
Speed (rev/min)	1549
Frequency (Hz)	50
Output control method	Pitch









This small wind energy converter is supplied pre-assembled. The individual assemblies – the rotor, drive train, two-piece mast – need only be joined together on the ground. Once the mast has been secured to the foundation, Monopteros is erected quite simply by just 2 or 3 men using the accompanying auxiliary strut and pulley! It is just as easy to lower the converter onto the ground again within a few moments for maintenance purposes. This practical wind energy converter can be put into operation once the guy cables and the likewise pre-assembled electrical installation have been con-

The rotor rotates even when there is only a slight breeze. The generator is connected in once a certain wind velocity – about 4 m/sec – has been reached. The converter then generates the required electrical energy at a constant rate of 100 rpm. The generator is switched off automatically if a wind speed of 19 m/sec is exceeded, and the rotor blade is put into parking mode. The rotor continues to rotate freely once in this position, as it withstands extreme wind speeds best in this way.

Service life of over 20 years

tures for operation on an island or for completely autonomous applications – for instance in combination with salt-water conversion plants, groundwater pumps, or permanent power-supply sytems (hybrid operation) with diesel generators or batteries.

This rugged, absolutely reliable design was achieved by using proven production items – such as Cardan shafts as employed in the automotive industry, long-lived gears, and tested-out generators.

Incidentally, Monopteros is

POSTER SESSION

AN INVENTORY OF WIND TURBINES IN CANADA

David Hoffman
World Wind Communications Co.

Abstract

The number of wind generators erected in Canada since 1970 and their generating capacity is tabulated by province and territory to document progress in commercializing wind power technology in Canada.

Data for both the number-of-wind-turbines category and the generating-capacity category is broken down into four lesser categories: amount installed per year and accumulated from all previous years, amount dismantled each year and accumulated remainder, amount confirmed still in operation during 1987, and status unknown in 1987.

An analysis of trends illustrated by the tabulated data is undertaken and observations about apparent market trends are presented.

Introduction

Prior to the author's project (1) initiated 12 months ago, a national examination of commercially-manufactured windplant installations has never been formally undertaken. Provincially, a survey of installations in Alberta (2) and a summary for B.C. (3) was completed several years ago. But the market trends and equipment performance and reliability was known only by the suppliers of the equipment.

The author's project detected about 280 windplants totalling over 1,190 kilowatts that had been installed in Canada from 1970 until early 1987. These figures do not include prototypes erected for the National Research Council, at the Atlantic Wind Test Site or the Lethbridge Wind Energy Research Site. Between 72 and 91 of the machines were found to be operational, accounting for 600 to 830 kW of capacity. Some 97 machines were found to have been dismantled or destroyed, while the status of the remaining 92 units was not determined.

Information about many of the machines in the national survey came from the equipment owners themselves. One hundred people responded to a questionaire sent out by the author within the time limits of the project.

Further information obtained by the author since the end of the survey, including information on new wind turbine installations, has been incorporated into the database originally constructed during the survey.

Summary

Since 1970, 258 windplants (except prototypes as categorized above, and except for machines of unknown generating capacity) totalling over 1,370 kW have been installed across Canada. The annual rate of installations and dismantlings for the whole country is illustrated in table 1. Eighty-nine of these units, totalling over 170 kW, have reportedly been dismantled over the period, leaving 169 units totalling 1,195 kW possibly still standing. The status of 57 units (159 kW) out of the 169 machines is not known but the remaining 113 units (1,025 kW) are confirmed to be operational or about to be operational again after an interruption in service.

Analysis

Table 1 reveals how the rate of new installations has remained above 10 units per year since 1979, and more importantly, how over 100 new kilowatts have been installed each year since 1983. The number of new units installed per year has fallen from 29 units in 1983 to 18 units in 1986 although the amount of new generating capacity installed per year during the period has risen, indicating that larger machines are being installed and the installation of smaller machines is dropping off.

Nearly all the machines installed during the 1970s were small (under 5 kW) battery-charging turbines used in remote power applications. One 'bulge' in the number of new units installed occouring during 1975, as seen in Table 1, can be attributed to a number of machines installed in northern Alberta and in the Beufort Sea north of the Yukon Territories by the petroleum industry. These units were used in temporary applications and were soon dismantled, which is why their numbers do not remain in the accumulated-units category of the table in later years. Otherwise, the number of new units installed per year remains below 10 units from 1970 to 1977. The higher numbers of new installations during the following few years can be considered as a consumer response to the rapid rise in oil costs and an increase in awareness of the availability of commercially-manufactured small wind turbines.

Another statistical 'bulge' in Table 1 is found in the new-capacity category during 1979. This can be attributed to a single 200 kW machine installed by the Nova Scotia Power Co. for demonstration purposes. With the exception of that anomality, it is revealed that more new generating capacity was installed in Canada during 1986 and 1987 than in any previous year. Indeed, when new machines being installed this year but not yet included in these statistics (4) begin operation, the new-capacity installation figures for 1987 will be higher than 1986.

Provincial markets

British Columbia had the highest level of installations during the 1970s followed by Nova Scotia and Ontario through the mid-1980s. The west coast market consisted of small battery-charging systems bought for remote residences and also by the Coast Guard for its lighthouse stations. This market activity peaked in 1979 and 1980 but has remained below five new units per year since then.

The Nova Scotia market also consisted of residential battery-charging installations, plus a number of residential grid-connected installations as this technology became commercially available, but unlike consumers in B.C., Nova Scotians took advantage of financial incentives offered by federal and provincial governments during the early 1980s. Installations peaked in 1982 but fell off quickly afterwards, especially when the government incentives and their infrastructural support expired.

Ontario installations during the early 1980s followed a pattern similar to B.C., plus a number of systems intended primarily for heat-production. Installations have never risen above eight units per year but have steadily remained above five units per year since 1981.

In terms of the number of machines installed, the three above-mentioned provinces, plus Alberta, account for the majority of windplant installations in Canada. But in terms of generating capacity, Alberta has received the highest amount. Over 62% of new capacity installed in Canada during 1986 went to Alberta, almost all of it in the form of grid-connected wind turbines in the 20 to 70 kW capacity range.

Sources of the equipment

Foreign manufacturers account for about 70% of all commercially-manufactured windplants erected in Canada and domestic firms account for the rest of them. The difference is even higher on the basis of generating capacity. The Dunlite company based in Australia sold more windplants in Canada than any other manufacturer, some 50 units of 1, 2 and 5 kW capacity, followed by Dyna Technology, the American manufacturer of the 200 and 450-watt Wincharger series, at about 40 units.

Wellington Windpower Co. has the largest number of domestically-manufactured windplant sales in Canada at some 20 units, followed by Thermax on the basis of the number of machines detected in the national survey.

Market conditions

Sales of small battery-charging windplants may increase from the 17-year average of about 10 units per year as more institutional and commercial organizations find favor with the reliability of the hardware.

Sales of small grid-connected windplants below 15 kW capacity will only increase if the interconnection policies of electric utilities are reformed to reflect the costs that independently-owned generators displace, and if the wind power industry continues to manufacture machines in this size range.

Sales of grid-connected windplants above 15 kW are also subject to the conditions stated above for units under 15 kW except that the industry is much more likely to continue manufacturing machines in this size range, and units of this size and larger sizes are most likely to make use of the new Class 34 accellerated write-off incentives being introduced by the federal government.

Variations in the cost of petroleum is considered to be a prime motivation for the development of wind power technology during the 1970s. Today it can have a direct effect on the viability of windplant installations at sites where oil consumption is displaced, whether the application is grid-connected (i.e. Magdelen Islands, Quebec or Cambridge Bay, N.W.T.) or battery-charging. With oil cost inflation arrested to some degree, the introduction of new windplant installations in oil-saving applications has also been slowed.

The strongest market force for wind power today is the sale of electricity to power companies and to the consumers of power they deliver. This has been felt in the United States for six years, in Denmark and the Netherlands for five, in other European countries, in India and elsewhere for two to three years. It is also the reason why Alberta has the highest amount of installed windplant generating capacity in Canada aside from its wind speeds. The market is made possible when the elctric utilities are required to buy power from independent power producers at a price equivalent to the cost of building their own new powerplants, and when governments begin to treat small power producers on a more equal footing with other energy producers in terms of market price subsidies (5).

Footnotes

1 National Wind Technology Field Operation Assessment, by World Wind Communications, 1987, Energy, Mines and Resources Canada.
2 A report on installations in Alberta prior to 1982 completed by David Baker for the Alberta Research Council, available from the Alberta Dept. of Energy.
3 An Assessment of Wind Energy Exploitation in British Columbia by ESL Sciences and IBI Group, Report ECR-81-2, 1981, B.C. Ministry of Energy, Mines and Petroleum Resources.
4 A 65 kW grid-connected machine due to be erected at Ft. McLeod, Alberta, two 10 kW grid-connected machines just installed at Hall Beach, N.W.T. and a 17.5 kW heat-producing machine due to begin operation at Cambridge Bay, N.W.T.
5 The Private Power Option for Canada, by Passmore Associates International, 1987.

WIND TURBINE INSTALLATIONS IN CANADA 1970-87

Nonsenclature:

Conf.Op. -Confirmed to be operating in February 1987 or assumed operating for newer installations.
Disa./Acc.-Dismantled during that year/net accumulated installations.
Inst./Acc.-Installed during that year/gross accumulated installations.
Stat.Un. -Operational status unknown in February 1987.

NATIONAL

	Kilowatts				Units			
Year	Inst./Acc.	Disa./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Disa./Acc.	Stat.Un.	Conf.Op.
70	4.5/ 4.5	0/ 4.5	0	1	4/ 4	0/ 4	0	1
71	0/ 4.5	0/ 4.5	0	0	0/ 4	0/ 4	0	0
72	1.06/ 5.56	1/ 4.56	0.06	0	7/ 11	5/ 6	2	0
73	3.23/ 8.79	0/ 7.79	0.03	0	8/ 19	0/ 14	1	0
74	10.8/ 19.59	0/ 18.59	0	2.2	6/ 25	0/ 20	0	2
75	14.056/ 33.646	0/ 32.646	2	2.8	20/ 45	0/ 40	1	1
76	2.91/ 36.556	1.2/ 34.356	0	2.2	5/ 50	12/ 33	0	2
77	35.63/ 72.186	2.7/ 67.286	5.4	17	16/ 66	12/ 37	5	3
78	18.3/ 90.486	2.116/ 83.47	0	8.1	8/ 74	5/ 40	0	5
79	228.448/ 318.934	2.5/ 309.418	11.2	206.318	24/ 98	2/ 62	10	5
80	59.43/ 378.364	5.75/ 363.098	37.05	10.85	27/125	4/ 85	14	5
81	27.825/ 406.189	10.3/ 380.623	17	4.225	15/140	6/ 94	5	4
82	48.775/ 454.964	7.985/ 421.413	12.2	8	20/160	13/101	4	4
83	109.64/ 564.604	19.2/ 511.853	39.05	44.99	29/189	5/125	9	15
84	170.1/ 734.704	11.8/ 670.153	3	114.6	28/217	9/144	2	21
85	124.45/ 859.154	101.43/ 693.173	25	95.45	20/237	28/136	1	17
86	295.03/1,154.184	13/ 975.203	7.3	286.03	18/255	3/151	3	14
87	221.5/ 1,375.684	2/ 1,194.703	0	221.5	14/269	1/164	0	14
Total	1,375.684	179.781/1,194.703	159.29	1,025.263	269	105/164	57	113

ALBERTA

	Kilowatts				Units			
Year	Inst./Acc.	Disa./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Disa./Acc.	Stat.Un.	Conf.Op.
74	4.6/ 4.6	0/ 4.6	0	0	2 /2	0/ 2	0	0
75	1.2/ 5.8	0/ 5.8	0	0	12/14	0/14	0	0
76	0/ 5.8	1.2/ 4.6	0	0	0/14	12/ 2	0	0
77	0/ 5.8	0/ 4.6	0	0	0/14	0/ 2	0	0
78	3.5/ 9.3	0/ 8.1	0	1.5	2/16	0/ 4	0	2
79	4.8/ 14.1	0/ 12.9	0	4.5	2/18	0/ 6	0	2
80	5.2/ 19.3	0/ 18.1	0	2	3/21	0/ 9	0	1
81	5/ 24.3	2/ 21.1	5	0	1/22	1/ 9	1	0
82	0/ 24.3	0/ 21.1	0	0	0/22	0/ 9	0	0
83	1.8/ 26.1	1.2/ 21.7	0	1.8	2/24	1/10	0	2
84	61.5/ 87.6	0/ 83.2	0	51.5	5/29	0/15	0	4
85	31.65/119.25	6.6/108.25	0	31.65	5/34	3/17	0	5
86	185/ 304.25	10/ 283.25	0	185	3/37	1/19	0	3
87	25/ 329.25	0/ 308.25	0	25	1/38	0/20	0	1
Total	329.25	21/ 308.25	5	302.95	38	18/20	1	20

BRITISH COLUMBIA

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
70	2/ 2	0/ 2	0	1	2/ 2	0/ 2	0	1
71	0/ 2	0/ 2	0	0	0/ 2	0/ 2	0	0
72	0/ 2	0/ 2	0	0	0/ 2	0/ 2	0	0
73	0/ 2	0/ 2	0	0	0/ 2	0/ 2	0	0
74	6/ 8	0/ 8	0	2	3/ 5	0/ 5	0	1
75	10/ 18	0/ 18	2	0	5/10	0/10	1	0
76	2.1/ 20.1	0/ 20.1	0	2.2	2/12	0/12	0	2
77	4.6/ 24.7	0/ 24.7	2.4	0	5/17	0/17	3	0
78	4.6/ 29.3	0/ 29.3	0	2.6	2/19	0/19	0	2
79	20/ 49.3	0/ 49.3	11.2	0	17/36	0/36	10	0
80	26.85/ 76.15	1/ 75.15	18.5	5.85	13/49	1/48	8	3
81	2/ 78.15	2.5/74.65	0	2	1/50	2/47	0	1
82	0/ 78.15	2.2/72.45	0	0	0/50	2/45	0	0
83	4/ 82.15	0/ 76.45	0	0	2/52	0/47	0	0
84	5/ 87.15	6/ 75.45	0	6	1/53	3/45	0	1
85	5.2/ 92.35	21/ 59.65	0	3.2	3/56	10/38	0	2
86	11/ 103.35	2/ 58.65	0	9	4/60	1/41	0	3
87	6.2/ 109.55	2/ 72.85	0	6.2	3/63	1/43	0	3
Total	109.55	36.7/72.85	34.1	39.05	63	20/43	20	19

MANITOBA

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
82	0.4/ 0.4	0/ 0.4	0	0.4	1/1	0/1	0	0
83	25.04/25.44	0/ 25.44	16	9.04	6/7	0/7	0	0
84	0/ 25.44	0.4/25.04	0	0	0/7	1/6	0	0
Total	25.44	0.4/25.04	16	9.44	7	1/6	2	4

NEW BRUNSWICK

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
76	0.75/0.75	0/ 5.25	0	0	1/ 1	0/1	0	0
77	4.5/ 5.25	0/ 5.25	0	0	3/ 4	0/4	0	0
78	2/ 7.25	2/ 5.25	0	0	1/ 5	1/4	0	0
79	0/ 7.25	0.5/ 4.75	0	0	0/ 5	1/3	0	0
80	0/ 7.25	0.75/ 4	0	0	0/ 5	1/2	0	0
81	2/ 9.25	2/ 4	2	0	1/ 6	1/2	1	0
82	0/ 9.5	0/ 4	0	0	0/ 6	0/2	0	0
83	13.3/22.55	2/ 15.3	4.5	1.8	4/10	1/5	2	1
84	4.5/27.05	0/ 19.8	0	0	1/11	0/6	0	0
85	0/ 27.05	4.5/ 15.3	0	0	0/11	1/5	0	0
86	2/ 29.05	0/ 17.3	2	0	1/12	0/6	1	0
87	0/ 29.05	0/ 17.3	0	0	0/12	0/6	0	0
Total	29.05	11.75/17.3	8.5	1.8	12	6/6	4	1

NEWFOUNDLAND

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
83	4.25/4.25	0/4.25	2.45	1.8	3/3	0/3	2	1
Total	4.25	0/4.25	2.45	1.8	3	0/3	2	1

NORTHWEST TERRITORIES

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
82	3/ 3	0/ 3	3	0	1/1	0/1	1	0
83	17.5/ 20.5	0/ 20.5	0	17.5	1/2	0/2	0	1
84	0/ 20.5	0/ 20.5	0	0	0/2	0/2	0	0
85	4/ 24.5	0/ 24.5	0	4	1/3	0/3	0	1
86	0/ 24.5	0/ 24.5	0	0	0/3	0/3	0	0
87	100/ 124.5	0/124.5	0	100	4/7	0/7	0	4
Total	124.5	0/124.5	3	121.5	7	0/7	1	6

NOVA SCOTIA

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
74	0.2/ 0.2	0/ 0.2	0	0.2	1/ 1	0/ 1	0	1
75	0.03/ 0.23	0/ 0.23	0	0	1/ 2	0/ 2	0	0
76	0.06/ 0.29	0/ 0.29	0	0	2/ 4	0/ 4	0	0
77	0.03/ 0.32	0/ 0.32	0	0	1/ 5	0/ 5	0	0
78	0/ 0.32	0.09/ 0.23	0	0	0/ 5	3/ 2	0	0
79	200/ 200.32	0/ 200.23	0	200	1/ 6	0/ 3	0	1
80	2/ 203.32	0/ 202.23	2	0	2/ 8	0/ 5	2	0
81	14.225/216.545	2/ 214.455	7	1.225	7/15	1/11	2	2
82	20.625/237.17	4.025/231.055	9.2	7.6	10/25	3/18	3	4
83	11.8/ 248.97	0/ 242.855	10	0	2/27	0/20	1	0
84	5.7/ 254.67	2.1/ 246.455	2	3.7	8/35	2/26	1	7
85	2.8/ 257.47	3.63/ 245.625	0	2.8	2/37	3/25	0	2
86	8/ 265.47	0/ 253.625	0	8	1/38	0/26	0	0
87	0/ 265.47	0/ 253.625	0	0	0/38	0/26	0	0
Total	265.47	11.845/253.625	30.2	223.525	38	12/26	9	18

ONTARIO

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
70	2/ 2	0/ 2	0	0	1/ 1	0/ 1	0	0
71	0/ 2	0/ 2	0	0	0/ 1	0/ 1	0	0
72	0.06/ 2.06	0/ 2.06	0.06	0	2/ 3	0/ 3	2	0
73	0.03/ 2.09	0/ 2.09	0.03	0	1/ 4	0/ 4	1	0
74	0/ 2.09	0/ 2.09	0	0	0/ 4	0/ 4	0	0
75	0.026/ 2.116	0/ 2.116	0	0	0/ 4	0/ 4	0	0
76	0/ 2.116	0/ 2.116	0	0	0/ 5	0/ 5	0	0
77	26.5/ 28.616	0.5/ 28.116	3	17	7/12	1/11	2	3
78	2.2/ 30.816	0.026/ 30.29	0	0	1/13	1/11	0	0
79	1.848/32.664	2/ 30.138	0	0.018	3/16	1/13	0	1
80	6.88/ 39.544	2/ 35.018	0.05	3	6/22	1/18	2	1
81	3.3/ 42.844	1.8/ 36.518	3	0	2/24	1/19	1	0
82	0.2/ 43.044	0.06/ 36.658	0	0	1/25	2/18	0	0
83	16.95/ 59.994	2/ 51.608	0.1	12.05	8/33	1/25	1	5
84	41.4/ 101.394	2.8/ 90.208	0	36.4	8/41	2/31	0	7
85	15.7/ 117.094	8.7/ 97.208	0	13.7	6/47	4/33	0	6
86	11.03/128.124	1/ 107.238	5.3	6.03	6/53	1/38	2	4
87	65.3/ 193.424	0/ 172.538	0	65.3	5/58	0/43	0	5
Total	193.424	20.886/172.538	11.54	153.498	58	15/43	11	32

PRINCE EDWARD ISLAND

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
70	0.5/ 0.5	0/ 0.5	0	0	1/1	0/1	0	0
71	0/ 0.5	0/ 0.5	0	0	0/1	0/1	0	0
72	0/ 0.5	0/ 0.5	0	0	0/1	0/1	0	0
73	0/ 0.5	0/ 0.5	0	0	0/1	0/1	0	0
74	0/ 0.5	0/ 0.5	0	0	0/1	0/1	0	0
75	2.8/ 3.3	0/ 3.3	0	2.8	1/2	0/2	0	1
76	0/ 3.3	0/ 3.3	0	0	0/2	0/2	0	0
77	0/ 3.3	0/ 3.3	0	0	0/2	0/2	0	0
78	0/ 3.3	0/ 3.3	0	0	0/2	0/2	0	0
79	1.8/ 5.1	0/ 5.1	0	1.8	1/3	0/3	0	1
80	0/ 5.1	0/ 5.1	0	0	0/3	0/3	0	0
81	1/ 6.1	0/ 6.1	0	1	1/4	0/4	0	1
82	0/ 6.1	0/ 6.1	0	0	0/4	0/4	0	0
83	1/ 7.1	0/ 7.1	0	1	1/5	0/5	0	1
84	28/ 35.1	0.5/34.6	0	3	2/7	1/6	0	1
85	40.1/75.2	25/ 49.7	0	40.1	2/9	0/7	0	1
86	0/ 75.2	0/ 49.7	0	0	0/9	0/7	0	0
87	0/ 75.2	0/ 49.7	0	0	0/9	0/7	0	0
Total	75.2	25.5/49.7	0	49.7	9	2/7	0	7

QUEBEC

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
73	2/ 2	0/ 2	0	0	1/ 1	0/1	0	0
74	0/ 2	0/ 2	0	0	0/ 1	0/1	0	0
75	0/ 2	0/ 2	0	0	0/ 1	0/1	0	0
76	0/ 2	0/ 2	0	0	0/ 1	0/1	0	0
77	0/ 2	0/ 2	0	0	0/ 1	0/1	0	0
78	6/ 8	0/ 8	0	4	2/ 3	0/3	0	1
79	0/ 8	0/ 8	0	0	0/ 3	0/3	0	0
80	2/ 10	2/ 8	0	0	1/ 4	1/3	0	0
81	0.3/ 10.3	0/ 8.3	0	0	2/ 6	0/5	0	0
82	12.55/ 22.83	1.7/ 19.15	0	0	5/11	6/4	0	0
83	14/ 36.83	14/ 19.15	6	0	2/13	2/4	1	0
84	8/ 44.83	0/ 27.15	0	0	1/14	0/5	0	0
85	25/ 69.83	20/ 32.15	25	0	1/15	4/2	1	0
86	73/ 142.83	0/ 105.15	0	73	2/17	0/4	0	2
87	0/ 142.83	0/ 105.15	0	0	0/17	0/4	0	0
Total	142.83	37.68/105.15	31	77	17	13/4	2	3

YUKON TERRITORIES

Kilowatts					Units			
Year	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.	Inst./Acc.	Dism./Acc.	Stat.Un.	Conf.Op.
72	1/ 1	0/ 1	0	0	5/5	0/5	0	0
73	1.2/2.2	0/ 2.2	0	0	6/11	0/11	0	0
77	0/ 2.2	2.2/0	0	0	0/11	11/0	0	0
84	1/ 3.2	0/ 1	1	0	1/12	0/1	1	0
Total	3.2	2.2/1	1	0	12	11/1	1	0

TABLE OF OPERATIONAL WIND GENERATORS IN CANADA, SEPTEMBER 1987

NONMENCLATURE:

Role: Ba-battery-charging, Co-commercial power, Fa-farm power,
Gr-grid-connected, He-electrical heat production,
In-instition power, NA-navigational aid power,
Re-residence power, TC-telecommunications power

Types: AG-Andrews (Canadian), B-Bergey Windpower (USA),
CA-Carter Wind Systems (USA), D-Dunlite Co. (Australia),
E-Enertech Co. (USA), HB-home-built design,
K-Heli-O-Beauce Co. (Canada), N-Northern Power (USA),
NO-Nordtank A/S (Denmark), S-Sencenbaugh Co. (USA),
T-Thermax Co. (Canada), W-Wicharger (USA),
Y-Wellington Windpower Co. (Canada)

TABLES:

ALBERTA

	Owner	Site	Type	Output KW	Year Installed	Role
1	Atwood	Cardston	E	5	1985	GrRe
2	C.B.C.	Pidgeon Mtn.	N	2	1983	BaTC
3	Cdn.W.Nat.Gas	Plateau Mtn.	N	2	1980	BaTC
4	Double A Fertil.	Lethbridge	CA	25	1987	GrCo
5	Eastridge School	Cardston	E	60	1986	GrIn
6	Eastridge School	Cardston	E	60	1986	GrIn
7	Edworthy	Calgary	W	1.5	1983	BaRe
8	Edworthy	Calgary	E	1.8	1984	GrRe
9	Esso Resources	N. Alberta*	W	0.45	1985	BaTC
10	Esso Resources	N. Alberta*	T	0.2	1985	BaTC
11	Grant	Champion	J	3	1979	BaRe
12	Hargraves	Walsh	E	25	1985	GrFa
13	Leth	Taber	NO	65	1986	GrFa
14	Long	Calgary	J	1.8	1979	BaRe
15	McCarthy	Cardston	E	5	1984	GrRe
16	Schuarte	Pincher Creek	E	5	1984	GrRe
17	Sinnott	Pincher Creek	E	40	1984	GrFa
18	Tatro	Trochu	B	1	1985	BaRe

18 units, 15 owners, 14 sites, 8 types, 303.75 kW, 1979-87.

*-One of these two units is sited at Swan Hills.

BRITISH COLUMBIA

	Owner	Site	Type	Output KW	Year Installed	Role
1	Anderson	Lasqueti I.	W	0.2	1986	BaRe
2	Anderson	Lasqueti I.	J	2	1981	BaRe
3	Barrett	Lasqueti I.	W	0.2	1987	BaRe
4	B.C. Tel. Co.	Calvert I.	N	3	1985	BaTC
5	B.C. Tel. Co.	Calvert I.	N	3	1986	BaTC
6	B.C. Tel. Co.	Swindle I.	N	3	1986	BaTC

B.C. table continued on next page

B.C. table continued from previous page

7	C.C.G.	Portlock Pt.	D	1	1970	BaNA
8	C.C.G.	Roberts Bank	D	2	1978	BaNA
9	C.C.G.	Prince Rupert	N	3	1986	BaNA
10	Churchill	Lasqueti I.	W	0.65	1980	BaRe
11	Haukedal	Lasqueti I.	W	0.2	1985	BaRe
12	Howard	Dunster	D	2	1976	BaRe
13	Swets (A)	Dunster	D	2	1987	BaRe
14	Swets (B)	Dunster	D	2	1974	BaRe

14 units, 9 owners, 12 sites, 4 types, 24.7 kW, 1970-87.

NEW BRUNSWICK

	Owner	Site	Type	Output KW	Year Installed	Role
1	Noel	Tracadie	E	1.8	1983	GrRe

1 unit, owner, site, and type, 1.8 kW, 1983.

NORTHWEST TERRITORIES

	Owner	Site	Type	Output KW	Year Installed	Role
1	N.C.P.C.	Cambridge Bay	CA	25	1987	GrCo
2	N.C.P.C.	Cambridge Bay	CA	25	1987	GrCo
3	N.C.P.C.	Cambridge Bay	CA	25	1987	GrCo
4	N.C.P.C.	Cambridge Bay	CA	25	1987	GrCo

4 units, 1 owner, 1 site, 1 type, 100 kW, 1987.

NOVA SCOTIA

	Owner	Site	Type	Output KW	Year Installed	Role
1	Browning	Wolfville	W	1.2	1984	BaRe
2	Gourd	Eureka	W	0.45	1984	BaRe
3	Gourd	Eureka	W	0.45	1984	BaRe
4	Gourd	Eureka	W	0.45	1984	BaRe
5	Gourd	Eureka	W	0.45	1984	BaRe
6	Gourd	Eureka	W	0.45	1984	BaRe
7	Gourd	Eureka	W	0.45	1984	BaRe
8	Henderson	Baddeck	D	2	1982	BaRe
9	Kadlec	Halifax	K	8	1986	HeRe
10	Krausse	Bedford	E	1.8	1982	GrRe
11	Van Zutphen	Liverpool	S	1	1984	BaRe
12	Zimmerman	Great I.	J	1.8	1985	BaRe

12 units, 7 owners, 7 sites, 6 types, 17.6 kW, 1982-86.

ONTARIO

	Owner	Site	Type	Output KW	Year Installed	Role
1	Ball	Wellington	Y	5	1977	BaCo
2	Ball	Wellington	Y	10	1977	BaCo
3	Com. Rsch. Ctr.	Shirley Bay	AG	0.018	1979	BaTC
4	Com. Rsch. Ctr.	Shirley Bay	T	0.1	1984	BaTC

Ontario table continued on next page

Ontario table continued from previous page

5	Com. Rsch. Ctr.	Shirley Bay	AG	0.03	1986	BaTC
6	Courtney	Maberly	J	3	1980	BaRe
7	Gray	Ottawa	HB	0.25	1983	BaRe
8	Kidd	Maberly	Y	1.2	1983	BaRe
9	Kortright Ctr.	Kleinberg	Y	10.5	1983	BaIn
10	Kortright Ctr.	Kleinberg	T	0.1	1985	BaIn
11	McKinnon	Thunder Bay	T	0.1	1983	BaRe
12	Motorola Co.	Kenora	T	0.1	1987	BaCo
13	Motorola Co.	Kenora	T	0.1	1987	BaCo
14	Motorola Co.	Kenora	T	0.1	1987	BaCo
15	Ont. Hydro	Ft. Severn	HO	60 kW	1987	GrCo
16	Ont. Nat. Res.	Winisk	B	10	1984	BaIn
17	Parker	Bryanston	Y	5	1985	BaRe
18	Plowright	Barry's Bay	Y	8	1985	BaRe
19	Science North	Sudbury	N	2	1986	BaIn
20	Shore	Sutton	Y	3	1986	BaRe
21	Smith	Picton	Y	20	1984	HeRe
22	Tratnen	Belfontaine	HB	1	1986	HeCo
23	Umanetz	Hanover	J	2	1985	BaRe
24	Watson	Rexdale	HB	0.5	1985	BaCo
25	Wesseling	Tobermory	Y	3	1984	BaRe
26	Winter	Reaboro	Y	5	1987	BaRe

26 units, 23 owners, 22 sites, 8 types, 150.1 kW, 1977-87

PRINCE EDWARD ISLAND

	Owner	Site	Type	Output KW	Year Installed	Role
1	Brown	Bunbury	B	1	1981	GrRe
2	Crawford	Cherry Hill	HB	3	1984	HeRe
3	P.E.I. En. Co.	Bunbury	E	40	1984	GrCo
4	Westisle School	Elmsdale	E	1.8	1979	GrIn
5	Wooton	Charlottetown	B	1	1981	BaRe

5 units, 5 owners, 5 sites, 3 types, 55.8 kW, 1979-84.

CANWEA 1987
Calgary, Alberta

September 28-29, 1987

ATLANTIC WIND TEST SITE ACTIVITIES

Carl Brothers

Abstract

The Atlantic Wind Test Site (AWTS) was established in Canada in 1981 to provide Canada with a facility to test and to aid in the development of wind related technology for Canadian application. This paper describes the site facilities, current and recent projects and discusses future activities and directions for the site.

Introduction

The AWTS in located at the extreme northern tip of Prince Edward Island (Figure 1). It consists of 185 acres of flat terrain bordered by a low cliff and exposed through 300 degrees to the Gulf of St. Lawrence (Figure 2).

The site experiences considerable salt corrosion, temperature variations of +/- 30 deg. C and an average windspeed of 6.25 m/sec. These conditions provide a severe operational environment, ideal for proof of concept testing.

The Institute of Man and Resources designed the site and now operates it under a ten year agreement with the government of Canada. Funding for the site is provided by paying clients and is supplemented by an annual contribution from the department of Energy, Mines and Resources.

Facilities and Staff

The test site has a main building that provides an operations centre for site activities. This earth sheltered lab houses the electronics lab, data processing centre, office space and emergency accommodations.

A mechanical shop located near the main building is equipped with typical maintenance and simple fabrication work.

The test site is arranged to allow tests to a number of machines simultaneously. The test pads run in a southwesterly direction across the site and are serviced by a 600 V 3 phase utility line that passes each site. Each site has a small building to house switching equipment and instrumentation.

The site has five full time staff members who carry out the wide range of work necessary.

Data Acquisition System

A state of the art data acquisition system has been in service at the AWTS for several years. The system consists of several field located data loggers with on board monitoring and data processing capabilities connected by an FM telemetry link to a base station IBM-AT microcomputer in the main laboratory building (Figure 3).

The field data loggers are Campbell Scientific CR21XL microloggers. These units monitor up to 16 single voltage input channels as well as four pulse input channels. Signal conditioning for volts, millivolts, DC/AC resistance, thermistor linearization and RH sensor linearization are available on each unit. Each logger can sample a full number of inputs at a preselectable scan rate and either store the raw data or perform preprogrammed standard data processing functions. This data, either raw or processed, may then be stored in final memory for manual interrogation or transmitted to the main computer.

The IBM-AT is equipped with appropriate software and hardware to enable automatic retrieval and processing of the data from the loggers on a daily basis and to retain the results on its 30 megabyte hard disk until the data is examined by the site data technician and appended to an appropriate test file.

In a typical application the loggers monitor the various inputs at a frequency of one hertz and store either one or ten minute averages as well as standard deviations, etc., in its final memory. The final memory is interrogated once a day by the base station IBM-AT.

The data may also be examined on a real time basis.

For dynamic analysis the data loggers have the capability of performing both high speed sampling and Fast Fourier Transformations (FFT).

Additional dynamic analysis can be done on the Hewlett Packard HP 1000 computer on loan to AWTS from the National Research Council of Canada for evaluation of an Indal 500 kW under study at AWTS.

Projects

1. Project Aquilo

The Indal 500 kW VAWT (Figure 4) originally erected at AWTS in 1983 suffered a blade failure in November of 1985. Subsequent to the failure the manufacturer redesigned the wind turbine struts to reduce the blade stresses in the strut/blade area. The modifications to the unit were carried out in the field by AWTS staff during early 1987. The unit was re-erected in March of 1987. Recommissioning tests have been completed and dynamic data has been collected over most of the operational windspeed range.

AWTS have recently commenced a one year program to evaluate the performance operat[illegible] and reliability of the modified unit. In addition some work will be carried out to investigate the effects of the large VAWT on electromagnetic interference.

The unit has a 36 M x 24 M rotor that rotates at 45 rpm. It is rated a 522 kW at 19 m/sec.

2. Wind/Diesel Development

Canada is fortunate to have substantial natural energy resources and as a result energy costs are quite low when compared to most of the world. However, much of Canada is sparsely populated and many remote communities are supplied by diesel generated electricity. It has long been recognized that the most immediate application for wind technology in Canada will be in these remote communities where diesel generators are used and where a good wind regime often exists (Figure 5).

Considerable work has been done in Canada on wind/diesel research in the past number of years. A demonstration unit consisting of two 50 kW diesel generators, a 35 kW Indal VAWT supplying power to a simulated community demand load, has been successfully operated in both hybrid and autonomous modes and with the wind turbine coupled to the diesels both mechanically and electrically. This unit, originally installed at Sudbury, Ontario, has been relocated to AWTS to continue development and testing. The present configuration is shown in Figure 6.

The system as installed at the AWTS will serve as a test bed for Canadian wind/diesel research and development. The facility will be accessible to qualified individuals or firms who are participating in the development of the technology.

The system is presently configured as indicated in Figure 7. The wind turbine, fitted with a 37 kW induction generator, can be operated either connected to the utility grid or to the diesel grid when wind/diesel tests are under way.

AWTS has purchased, installed and programmed a low cost programmable logic controller to allow adequate control over the 35 kW WECS under all operating conditions.

An IBM-PC based control system has been purchased which will eventually enable the system to function over a wide range of operating conditions as the technology develops ranging from low penetration wind to full penetration wind with short term storage. This control system also allows reasonably high levels of data acquisition for monitoring and analysis work. The IBM compatible computer is equipped with a modem to allow rapid transfer of operational data to any participating research institute.

3. Centre of Expertise

The AWTS has been recognized by the federal department of Energy, Mines and Resources (EMR) as a "Centre of Expertise". This contract enables AWTS to provide technical assistance and advice to EMR and any company in the wind energy field with such a requirement. Work is performed at the direction of EMR.

Two such projects are scheduled for installation at AWTS this fall for testing over the winter period.

Heli-o-beauce, a 25 kW horizontal axis machine manufactured in Quebec, will be erected in early October. The unit will be tested in autonomous operation over the fall and winter period to determine the performance characteristics. A general design review will also be carried out on the unit to identify areas of potential improvement.

Monopteros, a 25 kW single bladed horizontal axis machine made by MBB in Germany, will be marketed by Thermax of Van Kleek Hill, Ontario. The first unit in Canada will be installed at AWTS this fall for a period of performance and reliability testing. If the unit operates successfully, it is hoped to attempt some wind/diesel development work with the Monopteros in conjunction with the AWTS wind/diesel test bed.

4. Canadian Standards Association (CSA) Standards Development

CSA, in conjunction with various government and private institutions, has been developing standards for Canadian application of wind turbines over the past number of years. As a result of their efforts a proposed performance standard was issued in 1985.

During field tests designed to confirm the practicability of the standards several areas were found which required further study before criteria required to meet the standard could be specifically established. Work is continuing at the AWTS to resolve several of the noted deficiencies in the standard in both grid connected and battery charging turbines.

Future Activities

With the reduction in wind energy resource personnel available in Canada over the past several years and the development of technical expertise at AWTS since its operation began, the Atlantic Wind Test Site is playing an increasing role in the development of wind energy technology. Activities at the AWTS in past years were primarily focused on the testing of previously developed concepts. Activities for the upcoming year show AWTS to be playing a larger role in technology development with the wind/diesel test bed and the centre of expertise work.

It is anticipated that future work at AWTS will include considerable emphasis on the development of the technology, such as wind/diesel applications, with and without energy storage, and centre of expertise work. The installation and testing of newer, more cost effective machines will, of course, continue to be a major activity at the wind test site. Indal Technologies, for instance, will be upgrading Aquilo with a new 500 kW high energy rotor which will be installed at AWTS in late 1987.

Conclusion

The wind energy community in Canada has in the past several years adapted very well to changing realities in funding availability and public interest in renewable resources. A sense of optimism is again emerging in the community over the future of wind energy and the Atlantic Wind Test Site shares that optimistic outlook.

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2. L.A. Schienbein, Sudbury Wind/Diesel Report, Design, Development and Testing of a Vertical Axis Wind Turbine Assisted Diesel Generator System, March 1984.

3. Stephen L. Bolcso, Wind Energy Resource Assessment Seminar, National Research Council of Canada Report No. TM-WE-003, November 1980.

4. The Institute of Man and Resources, The Atlantic Wind Test Site, Wind/Diesel Research and Development Facility at the Atlantic Wind Test Site, August 1987.

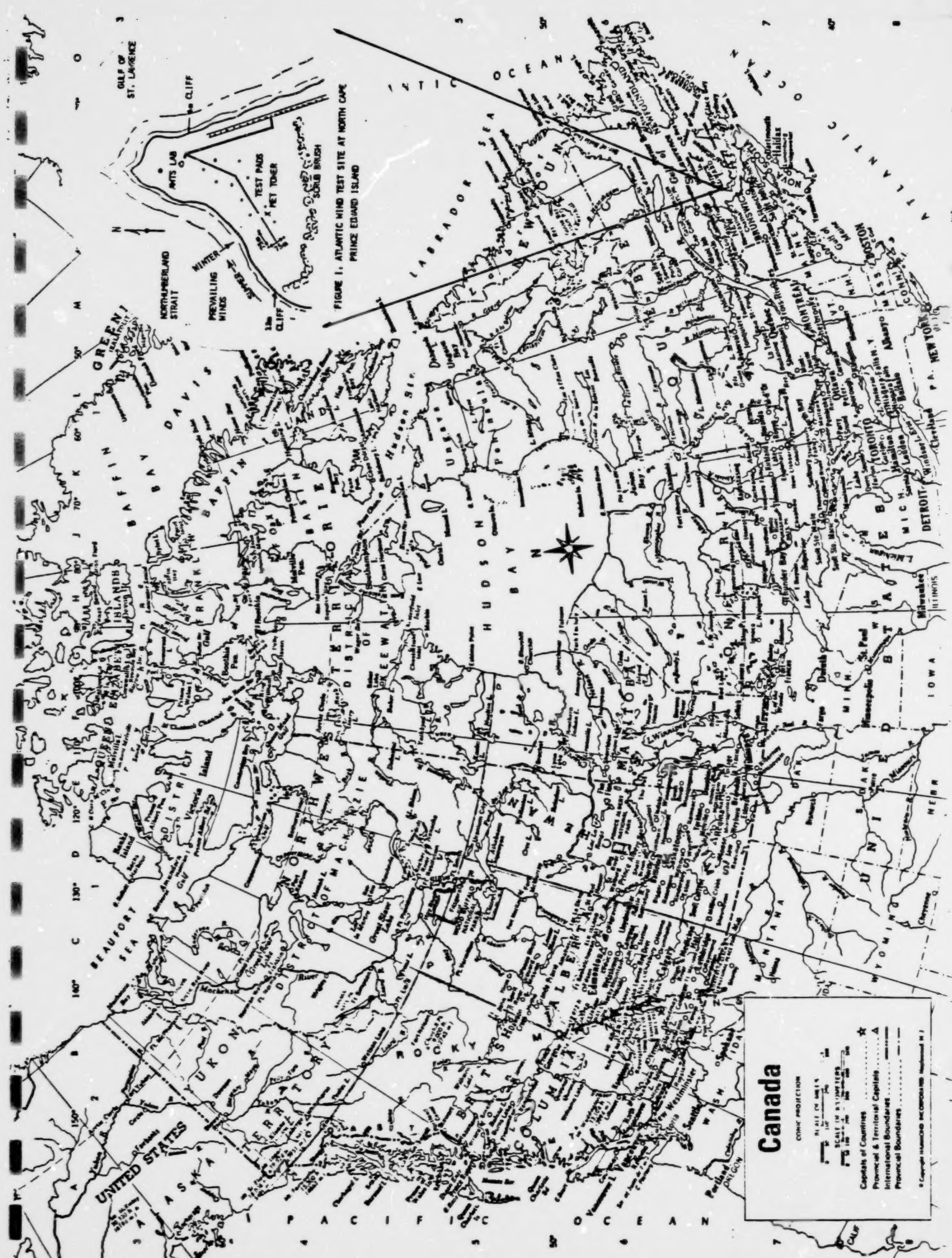

GULF OF ST. LAWRENCE
CLIFF
NORTHUMBERLAND STRAIT
N
PREVAILING WINDS
WINTER
SUMMER
AWTS LAB
TEST PADS
MET TOWER
SCRUB BRUSH
CLIFF
LABRADOR SEA
ATLANTIC OCEAN
HUDSON BAY
BAFFIN BAY
DAVIS STRAIT
BEAUFORT SEA
PACIFIC OCEAN
UNITED STATES
ALASKA
YUKON TERRITORY
BRITISH COLUMBIA
ALBERTA
MANITOBA
ONTARIO
QUEBEC
NEWFOUNDLAND
NOVA SCOTIA
NEW BRUNSWICK
MONTREAL
TORONTO
DETROIT
BOSTON
NEW YORK
Canada
CONIC PROJECTION
Capitals of Countries
Provincial & Territorial Capitals
International Boundaries
Provincial Boundaries

FIGURE 1. ATLANTIC WIND TEST SITE AT NORTH CAPE PRINCE EDWARD ISLAND

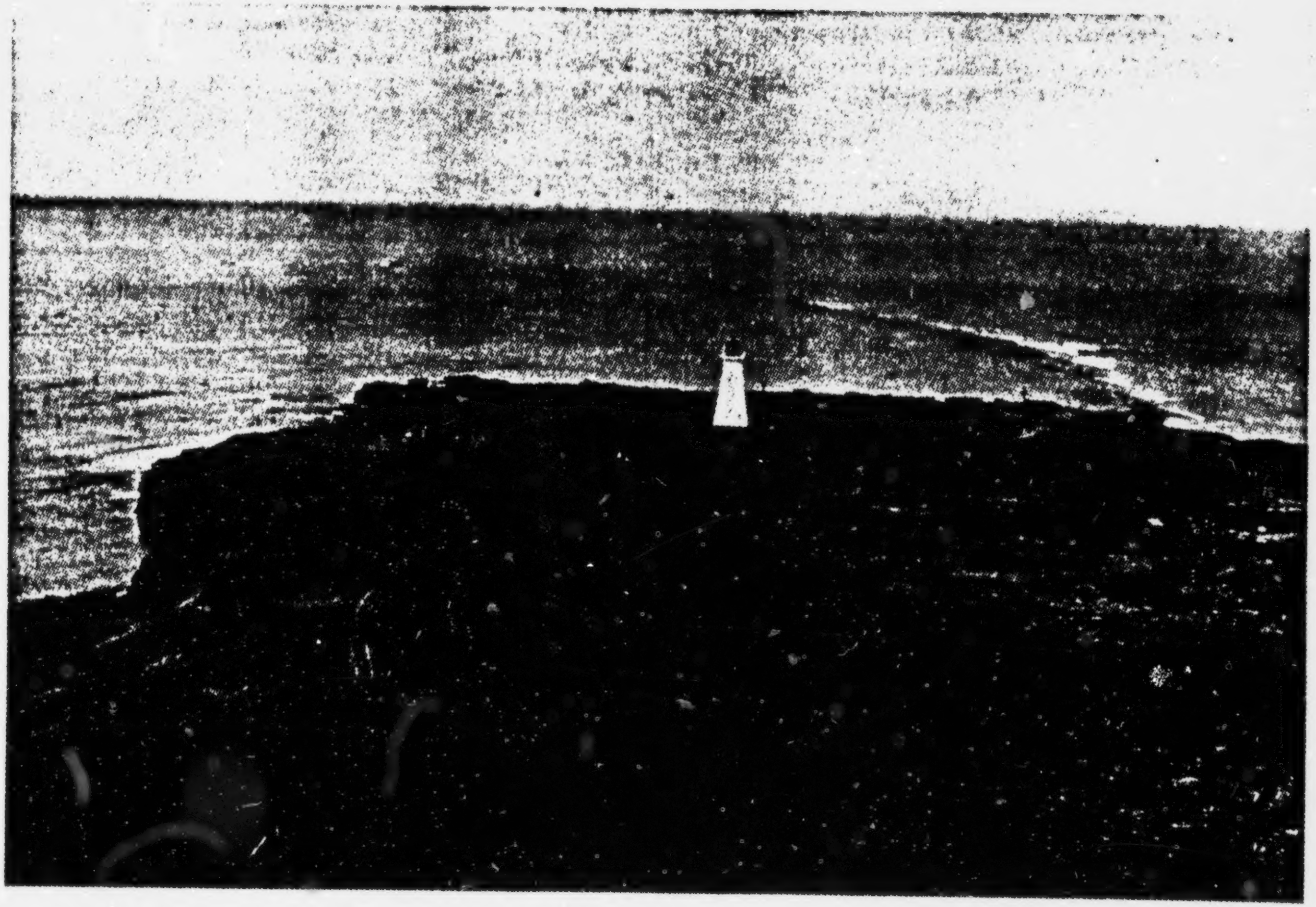
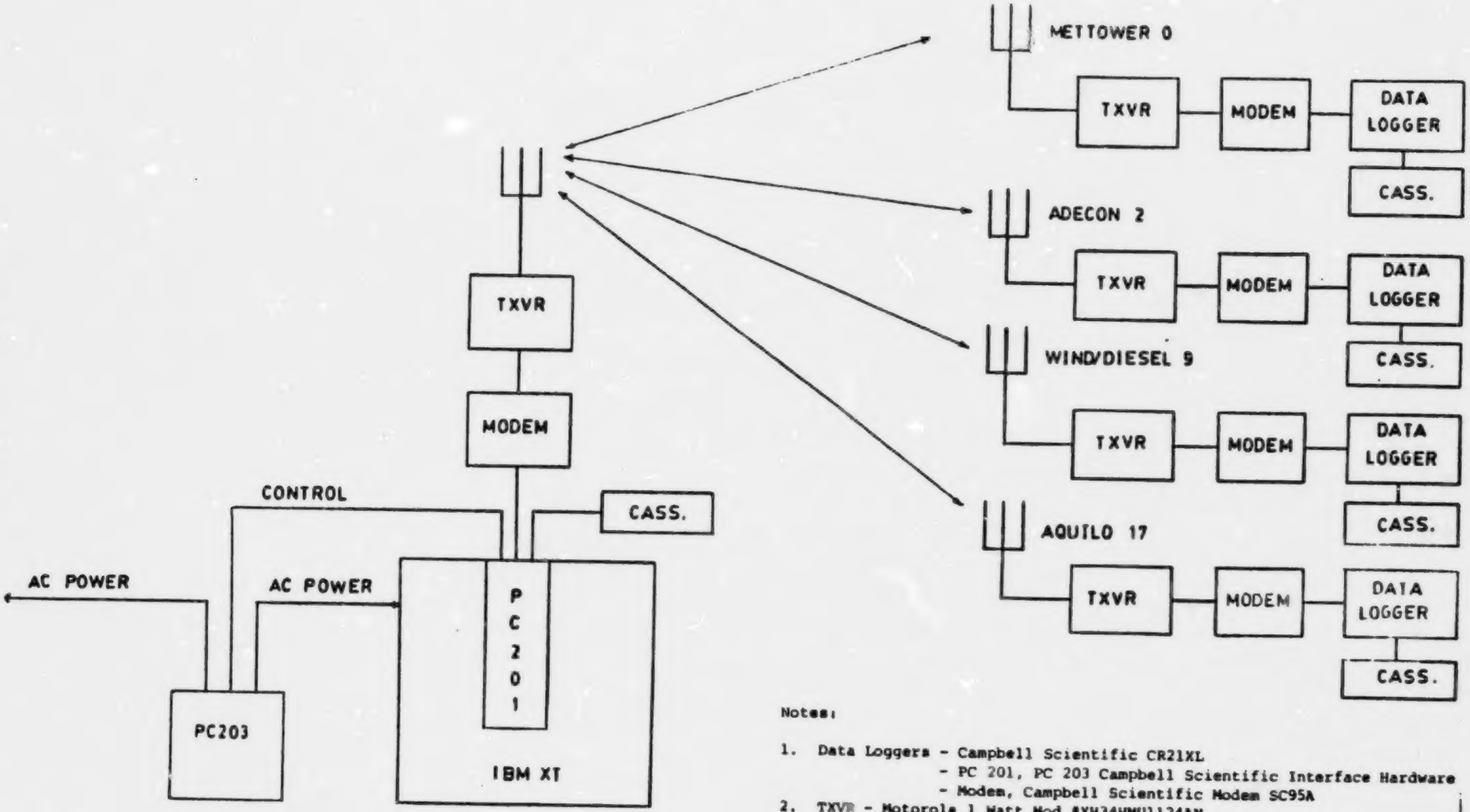


Figure 2. Aerial view of Atlantic Wind Test Site, Prince Edward Island


METTOWER 0
ADECON 2
WIND/DIESEL 9
AQUILO 17
TXVR
MODEM
DATA LOGGER
CASS.
CONTROL
AC POWER
AC POWER
PC203
PC201
IBM XT

Notes:

1. Data Loggers - Campbell Scientific CR21XL
   - PC 201, PC 203 Campbell Scientific Interface Hardware
   - Modem, Campbell Scientific Modem SC95A
2. TXVR - Motorola 1 Watt Mod #XH34HMU1124AN
3. CASS - Tandy CCR-82 Cassette Recorder

AWTS DATA ACQUISITION SYSTEM

atlantic wind test site	**Title:** AWTS Data Acquisition System		
	Dwg.No. S11	Project No. 29.01	
	Scale	Sheet 1 of 1	
Designed by	D/M/Y	**NOTES:**	
Drawn by GW	D/M/Y		
Checked by	D/M/Y		
Approved by	D/M/Y		

Figure 3

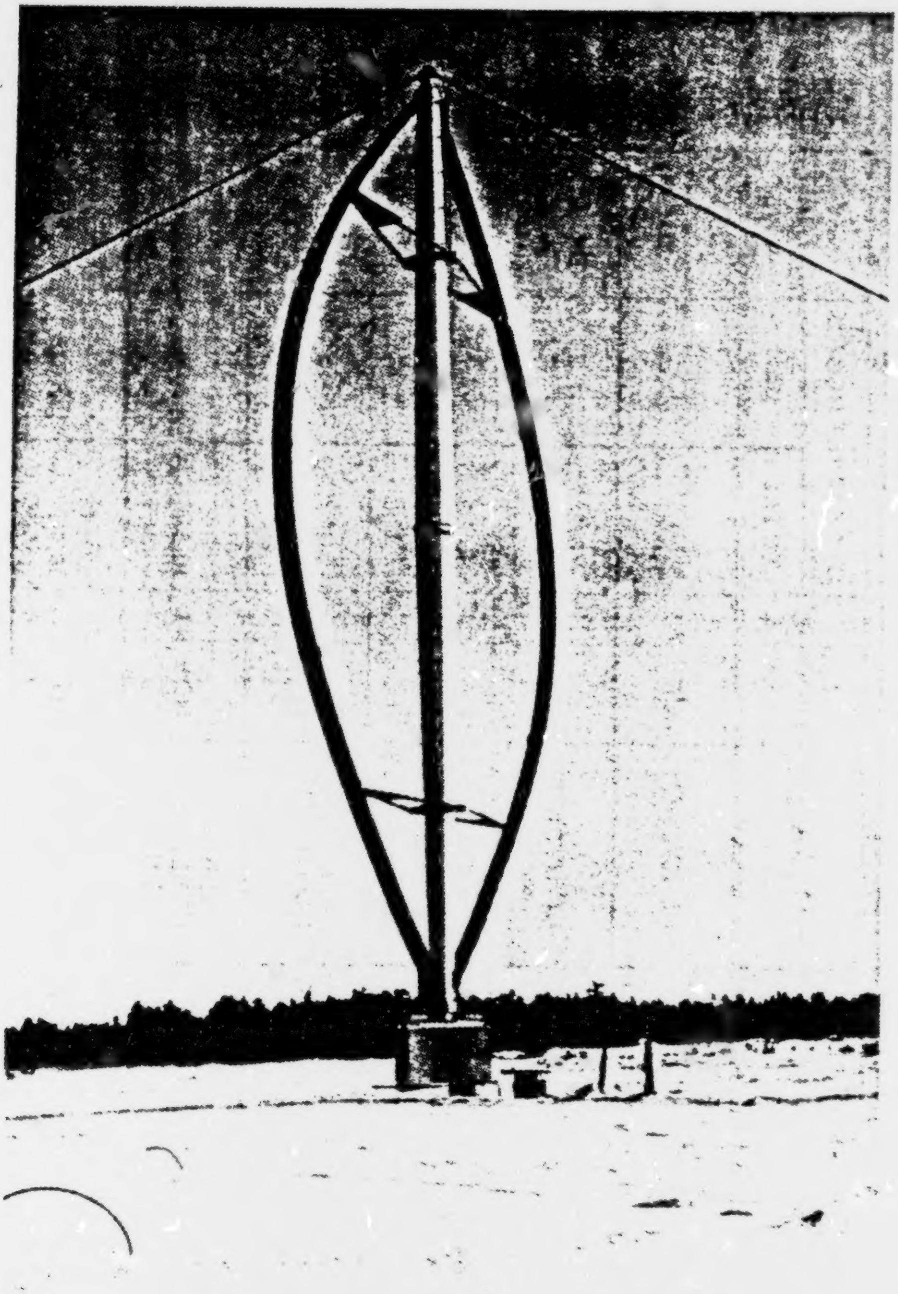
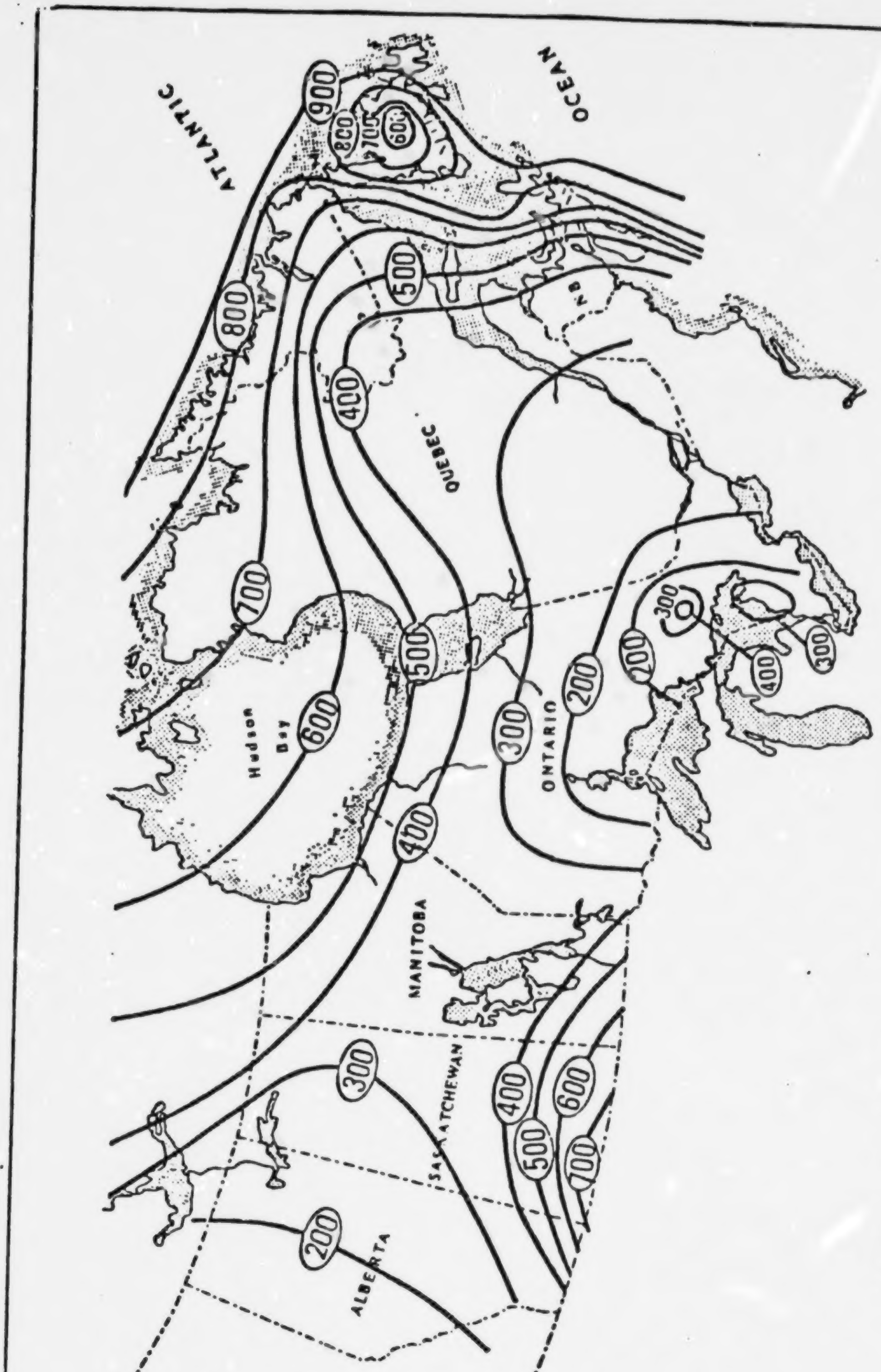


Figure 4. 500 kW prototype VAWT, Atlantic Wind Test Site


ATLANTIC
OCEAN
900
800
700
600
500
400
300
200
QUEBEC
Hudson Bay
ONTARIO
MANITOBA
SASKATCHEWAN
ALBERTA
BRITISH COLUMBIA
N.B.

ANNUAL AVERAGE WIND ENERGY DENSITY AT 50m ALTITUDE
WATTS/SQ. METRE

Figure. 5

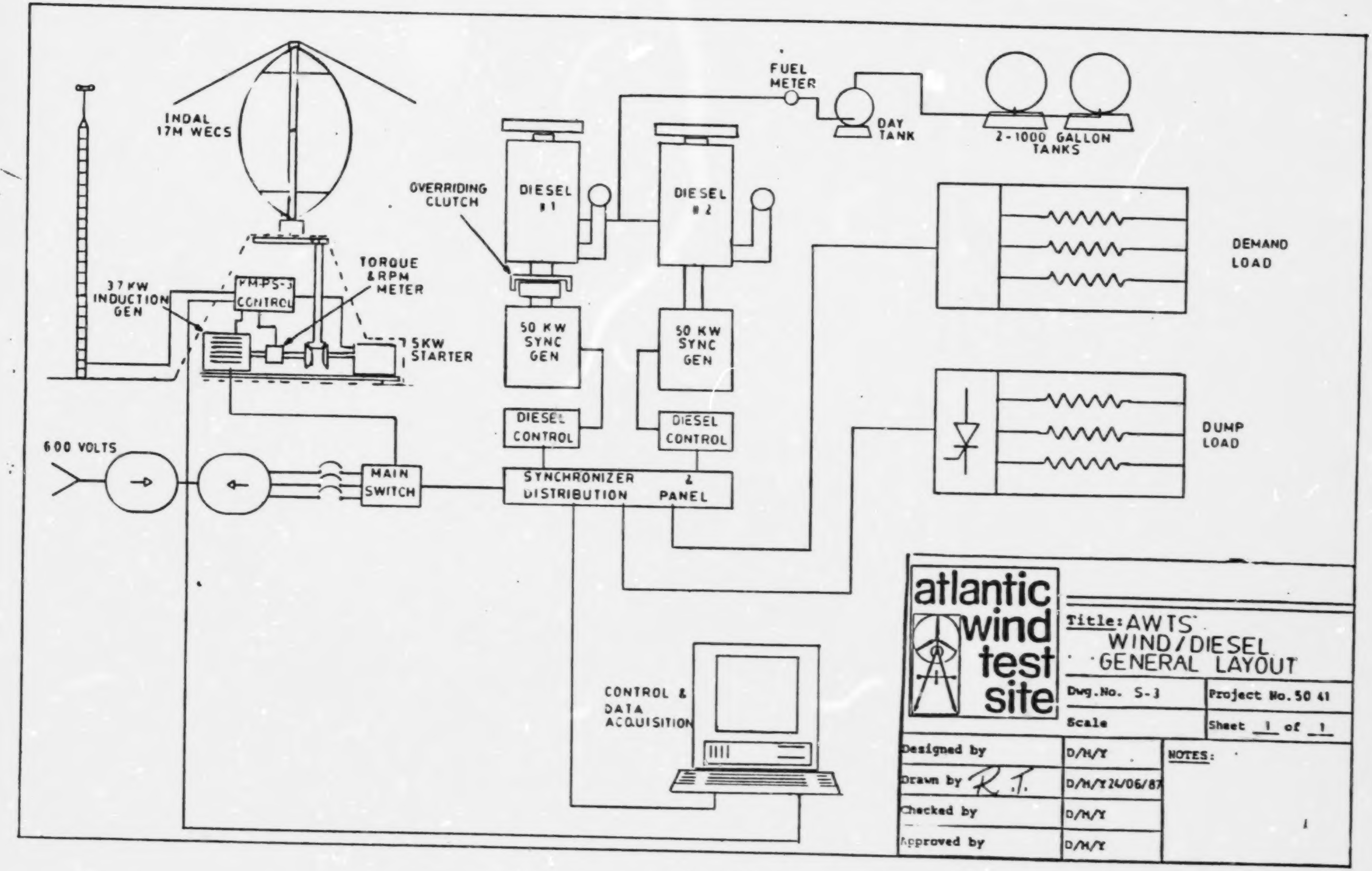

INDAL
17M WECS
37 KW
INDUCTION
GEN
VMPS-3
CONTROL
TORQUE
&RPM
METER
7.5KW
STARTER
OVERRIDING
CLUTCH
DIESEL
#1
DIESEL
#2
50 KW
SYNC
GEN
50 KW
SYNC
GEN
DIESEL
CONTROL
DIESEL
CONTROL
FUEL
METER
DAY
TANK
2-1000 GALLON
TANKS
DEMAND
LOAD
DUMP
LOAD
600 VOLTS
MAIN
SWITCH
SYNCHRONIZER
DISTRIBUTION
&
PANEL
CONTROL &
DATA
ACQUISITION
atlantic
wind
test
site
Title: AWTS
WIND/DIESEL
GENERAL LAYOUT
Dwg.No. S-3
Project No. 50 41
Scale
Sheet 1 of 1
Designed by
D/M/Y
Drawn by R.T.
D/M/Y 24/06/87
Checked by
D/M/Y
Approved by
D/M/Y
NOTES:

Figure 6

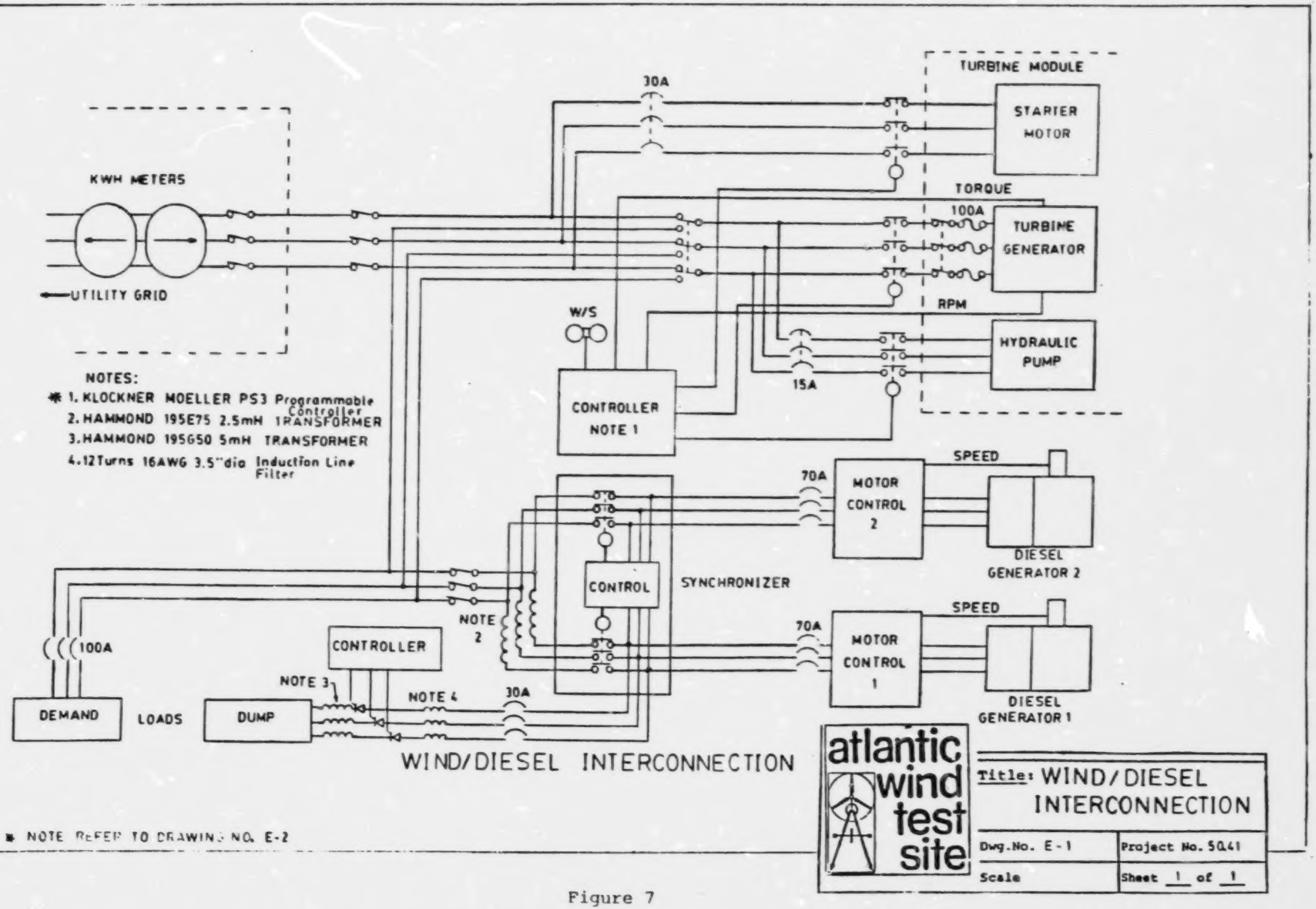

TURBINE MODULE
STARTER MOTOR
TORQUE
100A
TURBINE GENERATOR
RPM
HYDRAULIC PUMP
30A
15A
W/S
CONTROLLER NOTE 1
KWH METERS
UTILITY GRID
NOTES:
* 1. KLOCKNER MOELLER PS3 Programmable Controller
2. HAMMOND 195E75 2.5mH TRANSFORMER
3. HAMMOND 195G50 5mH TRANSFORMER
4. 12Turns 16AWG 3.5"dia Induction Line Filter
SPEED
70A
MOTOR CONTROL 2
DIESEL GENERATOR 2
CONTROL
SYNCHRONIZER
NOTE 2
SPEED
70A
MOTOR CONTROL 1
DIESEL GENERATOR 1
100A
CONTROLLER
NOTE 3
NOTE 4
30A
DEMAND
LOADS
DUMP
WIND/DIESEL INTERCONNECTION
* NOTE REFER TO DRAWING NO. E-2
atlantic wind test site
Title: WIND/DIESEL INTERCONNECTION
Dwg.No. E-1
Project No. 5041
Scale
Sheet 1 of 1

Figure 7

BY: John McKay

DEVELOPMENT OF WATER PUMPING WINDMOTORS

1. SUMMARY The development of water pumping aparatus is similar to the development cycle for any technology. The progress from inception of a new idea through development ,testing, marketing, and market acceptance, requires the commitment of cash, personnel, equipment, and management resources.

2. Introduction. Wind use for water pumping is several centuries old. Several types have been developed to meet the specific pumping requirements, and the available material technolgy. Types include:
    - drag type blades
    - lift
    - multi-blade or single
    - horizontal axis
    - vertical axis

3. Present The modern economic and technological demands have required manufacturers to adapt to meet new opportunities and restrictions. Systems can be provided for energy; either grid or stand alone power; grid or remote(mechanical or electric)

   Prime considerations in todays world are of economics, reliability, and useful life, with some increase in concern for environmental sensitivity.

4. Ideas To get an idea successfully to market, the idea must go through the following phases of its life cycle;

   IDEA---DEVELOPMENT--TESTING--MARKETING--ACCEPTANCE

   As an idea becomes more and more of a product during its development, the risk of its being found not economic becomes smaller and smaller, but the cumulative cost of getting it to that stage gets larger and larger.

5. Resources In the development process the following things will be needed in varying quantities and at varying costs;

technical expertise in that technology
legal advice in patents and contracts
labour to produce prototype products
facility in which to produce products
management of labour,cash, technology
sales representation
distribution service for product and advertising
establishing a service network
staff to examine and improve product

6. Financing Dollars will be required to obtain the resources needed to develop the ideas. Funds are available from several sources; friends
relatives
venture capitalists
private shareholders
public share offerings(VSE)

7. Public For those considering the development of new technology through the creation of a listed, public company, please take note of the following;

VSE now tries to maintain strict regulatory control of actions of any listed public company,
decisions of the company are subject to the review of the VSE and may not be binding
requirements exist for unallocated capital reserves
corporate legal requirements make it mandatory to retain expensive legal counsel
numerous reporting requiremnts make it necessary for large accounting fees
administrative cost to keep up with the reporting requirements are significant
promoters and brokers receive large shares of raised capital

8. General The above situation leads to the following guidelines;

a VSE company should gross $300,000 per year
the net revenue should be 10% of gross
company operations should not require rapid decision making to stay alive, as it cant be assured

9. Licences The issuance of technology licences can also cause problems in getting a product to market rapidly. In such situations, the licencor should get an iron-clad agreement with cash on signing, any options provided should be cash valued, and well defined, if royalties are included, performance of the licencee should be considered. Finally, the agreement should be well documented and legal.

10. Business The holder of the idea must decide whether they are developing ideas as a hobby, or to make money. To make money, the business plan is essential. It should include an analysis of the competition, the market, the method of prodution and distribution, as well as the cash flow and risks.

11. Summary The attached photos are of a novel new concept in the water pumping field. A low cost reliable system was patented developed, licensed, manufactured and distributed. The problems encounterd are classic in the consideration of risks involved in development of new products.

MAVERICK WIND PUMP TESTING

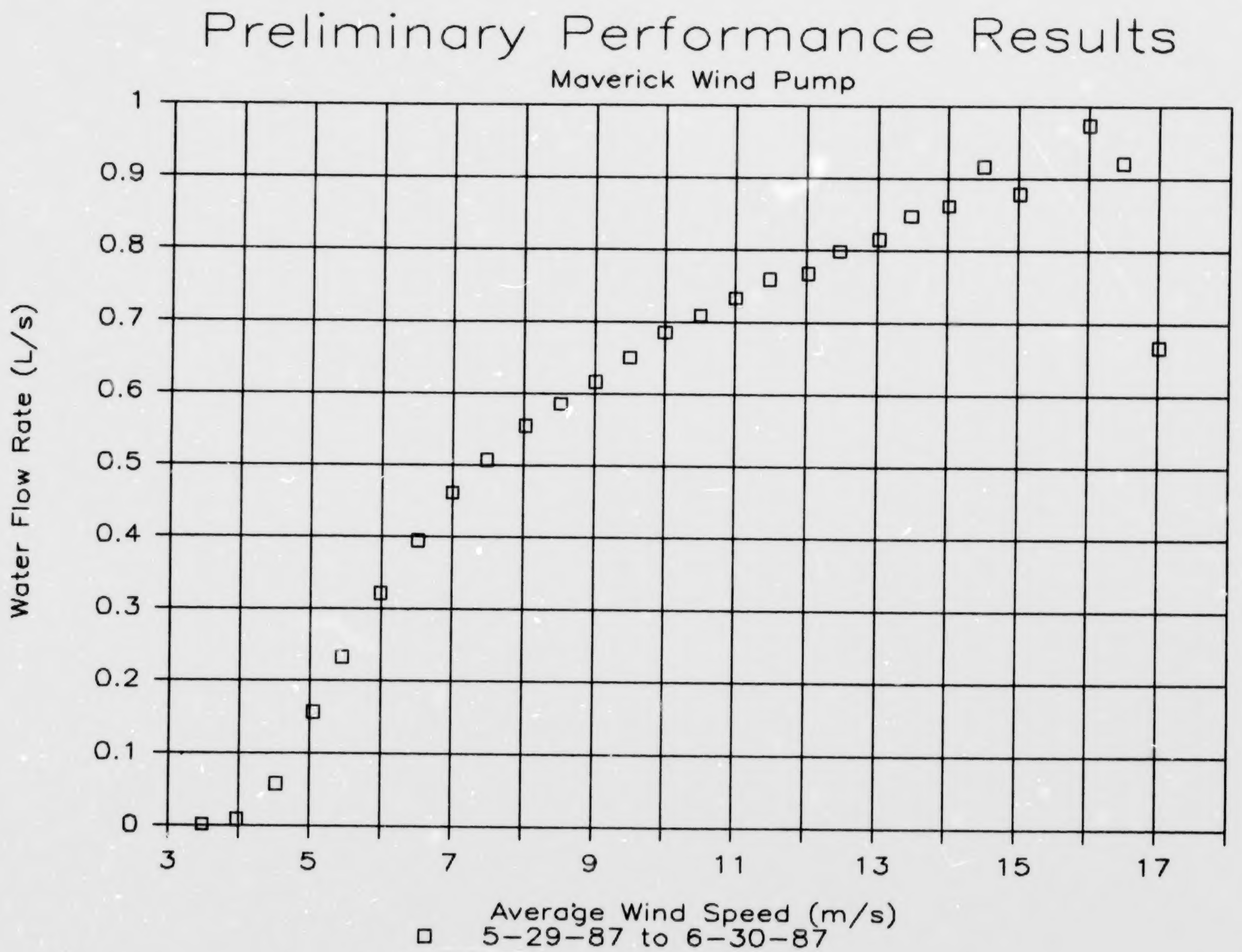
Mary-Ellen Jones, P.Eng.

The Preliminary Results of a performance test carried out in accordance to the CSA's Standard for the Performance Testing of WECS, was presented in poster form. The Maverick Wind Pump has been under test at the Massey facility in Fort Macleod since May 1987. Testing is being carried out on a unit that is installed at a well and pumps against a 22 ft. head. Wind speed, wind direction, atmospheric temperature, atmospheric pressure, WECS rpm and water flow rate are measured once per minute and stored as ten minute averaged data sets. Analysis of the final data and the complete Performance Test Report as outlined in the Standard will be available at a later date.

Preliminary Performance Results for Maverick Wind Pump
(May 29, 1987 to June 30, 1987)
by: Mary-Ellen Jones, P.Eng.

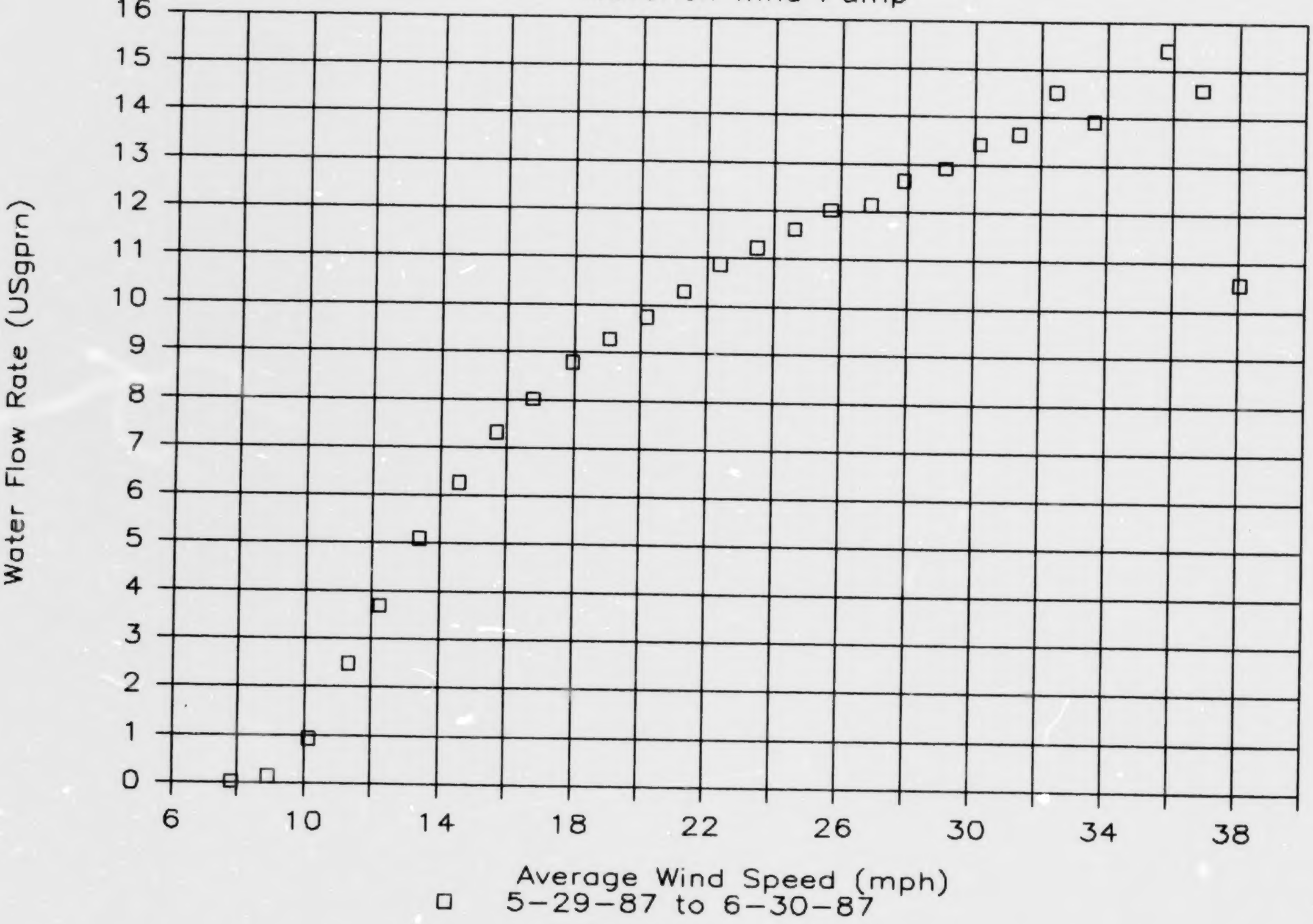
Bin No. (i)	Bin Itervals (m/s) to (m/s)	Number of Reduced Data Sets (n)	Air Temp. (C)	Air Pressure (kPa)	Air Density (kg/m3)	Maximum Wind Speed (m/s)	Average Wind Speed (m/s)	Average Wind Speed (mph)	Water Flow Rate (L/s)	Water Flow Rate (USgpm)	Average Rotor Speed (rpm)
1	3.25 to 3.75	75	19.12	90.60	1.080	6.38	3.49	7.80	0.002	0.029	20.7
2	3.75 to 4.25	63	20.03	90.60	1.077	6.57	3.98	8.90	0.009	0.140	31.4
3	4.25 to 4.75	73	21.95	90.40	1.067	7.13	4.53	10.13	0.058	0.924	75.6
4	4.75 to 5.25	99	22.14	90.10	1.063	9.70	5.05	11.29	0.157	2.481	142.8
5	5.25 to 5.75	111	21.27	90.08	1.066	8.58	5.46	12.21	0.233	3.697	179.8
6	5.75 to 6.25	112	19.41	90.00	1.072	8.89	5.99	13.39	0.322	5.109	226.9
7	6.25 to 6.75	94	18.94	90.00	1.073	10.14	6.51	14.56	0.395	6.265	247.1
8	6.75 to 7.25	96	17.97	89.90	1.076	9.16	7.00	15.66	0.461	7.313	253.5
9	7.25 to 7.75	96	17.97	89.90	1.076	10.33	7.48	16.74	0.506	8.021	272.0
10	7.75 to 8.25	103	19.16	89.80	1.070	11.52	8.02	17.95	0.554	8.787	272.8
11	8.25 to 8.75	132	19.87	89.80	1.068	13.73	8.52	19.06	0.586	9.281	257.4
12	8.75 to 9.25	122	19.08	89.64	1.069	13.17	9.01	20.16	0.616	9.763	252.2
13	9.25 to 9.75	131	18.14	89.73	1.073	12.62	9.51	21.27	0.650	10.301	280.9
14	9.75 to10.25	95	18.69	89.62	1.070	13.31	10.00	22.37	0.685	10.863	247.0
15	10.25 to10.75	105	18.03	89.63	1.072	13.65	10.50	23.49	0.709	11.236	288.9
16	10.75 to11.25	80	17.82	89.58	1.073	15.03	11.00	24.60	0.733	11.618	298.4
17	11.25 to11.75	80	18.28	89.65	1.072	15.67	11.48	25.68	0.759	12.027	290.7
18	11.75 to12.25	52	17.57	89.59	1.074	15.70	12.02	26.89	0.767	12.150	312.5
19	12.25 to12.75	49	18.02	89.62	1.072	15.65	12.47	27.88	0.798	12.653	292.2
20	12.75 to13.25	50	17.36	89.57	1.074	16.33	13.02	29.12	0.815	12.919	275.4
21	13.25 to13.75	24	19.26	89.48	1.066	16.96	13.48	30.15	0.847	13.426	234.3
22	13.75 to14.25	6	18.75	89.64	1.070	17.41	14.01	31.33	0.862	13.658	185.1
23	14.25 to14.75	8	23.87	89.58	1.051	18.09	14.50	32.44	0.917	14.531	198.2
24	14.75 to15.25	8	20.22	89.40	1.062	18.41	15.02	33.59	0.879	13.928	174.2
25	15.25 to15.75	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
26	15.75 to16.25	1	25.69	89.66	1.045	17.23	16.00	35.78	0.974	15.437	178.6
27	16.25 to16.75	1	21.73	89.12	1.053	17.58	16.49	36.89	0.921	14.599	170.5
28	16.75 to17.25	1	17.40	89.15	1.069	20.71	17.02	38.07	0.667	10.573	282.9

* Pumping Head = 22 ft


Preliminary Performance Results
Maverick Wind Pump
Water Flow Rate (L/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
3
5
7
9
11
13
15
17
Average Wind Speed (m/s)
□ 5-29-87 to 6-30-87

Preliminary Performance Results

Maverick Wind Pump



WATER PUMPING

DEVELOPING EXPORT MARKETS

Eric Jensen, P.Eng.
Jensen Engineering Ltd.

The Lethbridge Wind Research Site can assist in developing export markets for Canadian windpumps by the following services:

(1) Certified, independent testing of equipment to world test standards,

(2) Matching pumps and turbines for simulated conditions of well depth and discharge requirements,

(3) Demonstration of operational windpumps for potential buyers, government aid agencies and development banks.

CASE STUDY - ONE EXPORT SALE

The first export sale created by the Lethbridge test site occurred in March, 1987 when Canadian Agtechnology Partners Inc. sold one windpump for small-scale irrigation in the Caribbean.

By documenting the various stages of that transaction we gained some useful hints about operating in the export market, as illustrated in the following slide presentation:

1. Make sure your equipment works at home before considering export markets.
2. Get specific details of the buyers requirements and expectations.
3. If possible test your machine for the simulated application (pump selection and performance).
4. Design your machine for ease of container shipment.
5. Don't oversell your product. The customer may believe what you say.
6. Sell and operate one unit overseas before you look for bigger orders. Try to include a service contract.
7. If it breaks down, fix it as quickly as possible. Don't whine about it or try to get out of it.
8. Look for a partner overseas to keep your machine running. Provide training and spare parts.
9. Be prepared to lose $ on the first installation while you baby-sit it from 5,000 miles away.
10. Use your first successful installation as a local demonstration to develop the market in that region.

EVALUATION OF SMALL SCALE WIND TURBINES
FOR PUMPING WATER

B. A. Paterson, P.Ag.
Project Manager
Lethbridge Wind Research Test Site

For Presentation to:
Canadian Wind Energy Conference '87

September, 1987

INTRODUCTION

The second year of this three-year mandate for the Lethbridge Wind Research Site commenced April 1, 1986 and ended on March 31, 1987. Funding for the 1986-87 fiscal year's operation was provided from three sources, including: Alberta/Canada Energy Resources Research Fund - $47,000; Federal Department of Energy Mines and Resources - $50,000; Drainage Branch of Alberta Agriculture - $48,520.00. The objectives of the testing program are primarily to:

1) evaluate the potential for wind turbines to efficiently pump water for agricultural uses; and

2) monitor, demonstrate and evaluate various types of wind pumping equipment developed, manufactured or distributed in Alberta and Canada.

In addition the site has two solar pumping systems and one electric generating turbine under test. Data from these two units will be included in the report.

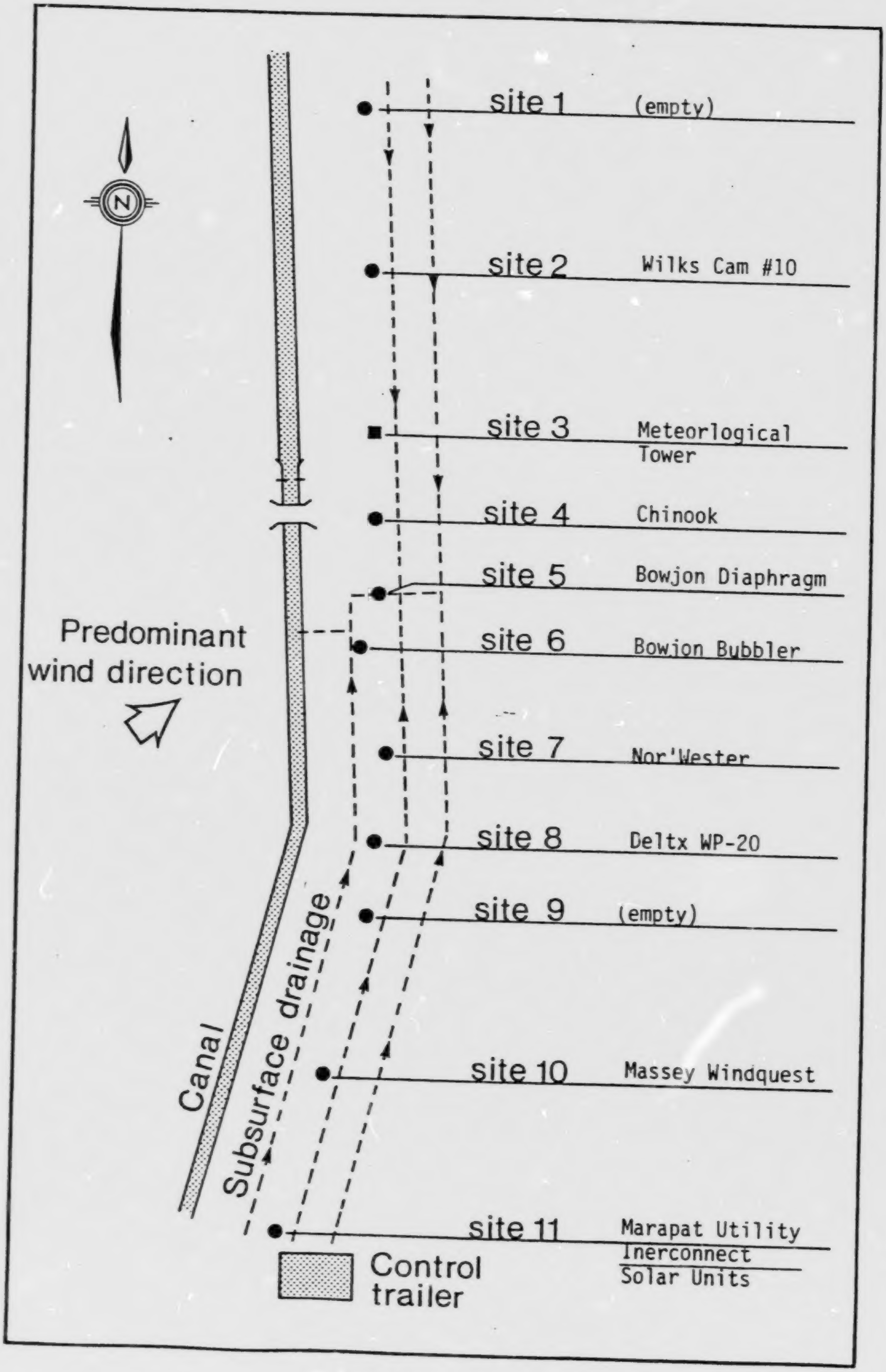
ACTIVITIES - 1986/87

A) Wind Turbines

During the 1986 test period, a total of eight wind turbines were installed at the site, including seven water pumping units and the one electric generating (12.5) kW machine (Figure 1). The turbines represent a good cross-section of machines currently on the market.

Model	Description	Manufacturer
Wilks Cam #10	multi-blade with piston pump	Wind Energy Unlimited, California
Chinook (7.5)	multi-blade with piston pump	Ensteel Ltd. Calgary, Alberta
Bowjon Ranger 2 units	multi-blade with air lift systems	Prairie Ditching (distributor) Lethbridge, Alberta
Maverick Windquest	X-blade with positive displacement pump	Massey Enterprises Fort MacLeod, Alberta
Deltx WP-20	delta blade with 2 piston pumps	Deltx Windpump Calgary, Alberta
Nor'Wester	two blade DC electric with battery storage	Nor'Wester Energy Calgary, Alberta
Marapat	three-blade DC electric with inversion to AC	Marapat Ltd., Stirling, Alberta

WINDMILL TEST SITE



site 1 (empty)
site 2 Wilks Cam #10
site 3 Meteorlogical Tower
site 4 Chinook
site 5 Bowjon Diaphragm
site 6 Bowjon Bubbler
site 7 Nor'Wester
site 8 Deltx WP-20
site 9 (empty)
site 10 Massey Windquest
site 11 Marapat Utility Inerconnect Solar Units
N
Predominant wind direction
Canal
Subsurface drainage
Control trailer

Figure 1

All but two of these machines were operational at various times throughout the testing season and were therefore monitored and preliminary performance curves were calculated. The two units not monitored were the WP-20 and the Nor'Wester since installation was not completed until after winterization of the site.

In addition, two solar pumping units were operational during the summer and fall. The units were manufactured by Cambrian Engineering Ltd. of Saskatoon, Saskatchewan and TPS Industries Ltd. of Toronto, Ontario. Both systems utilize photovoltaic panels hooked to DC pumps. Only the TPS Industries Ltd. unit was monitored; its performance analyses has not yet been completed.

MONITORING

A) Site Selection and Design

In order to provide a constant supply of water throughout the summer season, a site adjacent to a St. Mary River Irrigation District canal immediately east of Lethbridge was chosen as the test facility. The site, because of its location beside the canal, was affected by high water table and salinity problems due to canal seepage. A subsurface drainage system was therefore designed and installed in order to dewater the area plus provide a practical demonstration of actual field conditions in which the turbines would work.

To measure the pumping performance of the wind turbine and solar system, a closed-loop double sump system was installed. A schematic of the pumping circuit is shown in Figure 2. The unit being tested pumps water from one sump, up a predetermined distance and then into a vented standpipe. The piping used in this portion of the test circuit was sized to be consistent with actual field applications while presenting negligible dynamic head to the pump. The vented standpipe was used to separate air from the pumped water and to dampen the pulsating flows before draining through a flow metered pipe into the second sump. Each of the turbine-type flow meters were equipped with a flow rate register for local readout as well as a pickup for remote sensing. The metered pipe was designed to ensure valid flow readings. This required sloping the pipe to guarantee continuous submergence of the flow meter and sizing the pipe to decrease the turbulence in the pumped water before measurement. Also, the design ensured that the dynamic head developed in this section would not raise the water level in the standpipe to a point where it would contribute to the pumping head of the wind turbine. The water exiting the metered pipe provided potential users with visual evidence of the wind turbine capabilities. The loop was completed when the pumped water returned to the first sump through a connecting pipe located near the base of the two sumps.

B) Atmospheric Sensors

A Climatronics weather monitoring package is located on a 16 m tower near the center of the site. The package consists of:

1. Four horizontal wind speed sensors mounted at 7.0, 10.0, 12.8 and 16.5 m. The locations of the sensors were chosen such that the hub

PUMPING CIRCUIT

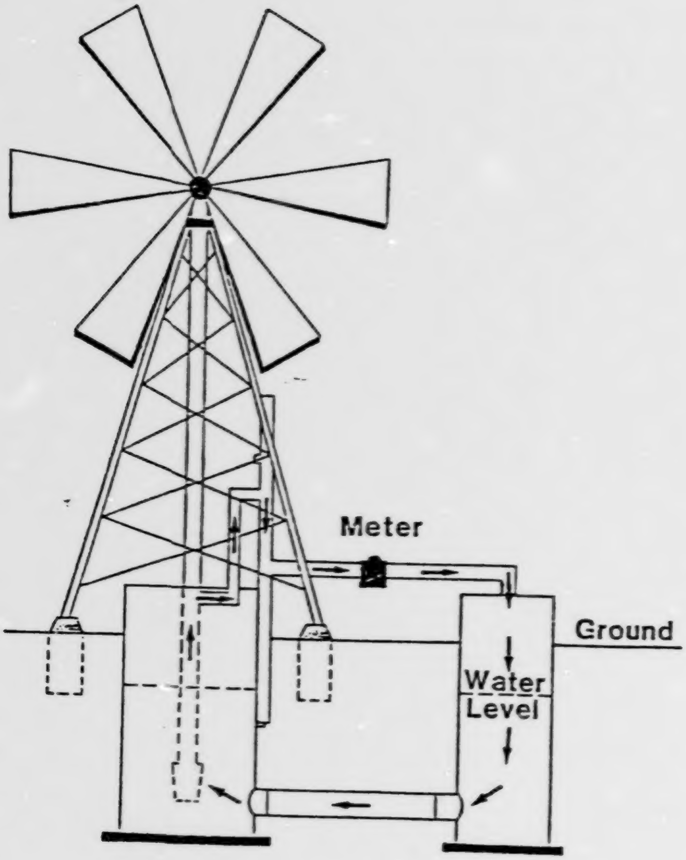

Meter
Ground
Water
Level

Figure 2

height of any wind turbine tested was within one metre of the height of a wind speed sensor.

2. One wind direction sensor mounted at 16.5 m. This sensor will be used to study the effect of wind direction on the performance of the units. (Wind direction effects could include wind speed 'shading' by nearby obstructions or wind speed profile changes due to nonhomogeneous terrain).

3. One ambient temperature sensor mounted at 10.0 m and one atmospheric pressure sensor mounted at 2.0 m. These sensors were used to determine the atmospheric air density such that the performance data could be normalized to a standard air density.

4. Local displays of the wind speed and direction at the 10.0 m level for demonstration purposes.

5. Signal conditioners such that all sensor outputs could be transmitted to the data acquisition system in a consistent manner.

6. One Kipp and Zonen solar radiation sensor located at and on the same inclination as the TPS Industries Ltd. solar pumper.

C) Data Acquisition

There are many parameters which can be measured to evaluate the performance of a solar unit and a wind turbine. It was decided that the performance variables of most interest to users and manufacturers were: the volume flow rate as a function of wind speed and solar energy; the variation of flow with pumping head and the predicted flow volumes in a given solar and wind regime. The manufacturer would also be interested in the overall performance characteristics and efficiency of his machine in order to make improvements to the design. In view of these priorities, along with budget and time constraints, it was decided to monitor pumping flow rates for each wind machine. During 1987 it is proposed that turbine rotor speed sensors will be added. More detailed performance tests will be possible for a wide variety of pumping heads upon completion of the deep well simulator. In addition, peak wind gusts were also measured at the site on the theory that turbine failure will more likely result from instantaneous high wind gusts than from sustained high average winds. Only pumping volume versus solar radiation was measured at a given head for the solar unit.

D) Monitoring System

During the 1985/86 fiscal year a considerable amount of time was spent in changing the monitoring system over from the original ISIS computer to an IBM computer system. This changeover was necessary because of the high maintenance costs associated with the ISIS unit, its low operational efficiency and small size. The ISIS computer has also been phased out by the manufacturer and parts were impossible to obtain. The changeover to the IBM system continued in the 1986/87 fiscal year and a software package has been prepared which allows for rapid, accurate monitoring of a large number of parameters.

The IBM system uses a SAFE 8000 data acquisition unit for collecting and averaging field data. It is presently configured to accept up to 20 pulse inputs, 32 analog inputs, and 16 digital inputs. It can also generate four 0-10 volt analog outputs. The SAFE and the IBM are housed in an environmentally controlled trailer located at the south end of the test site. Its components are shown in Figure 3.

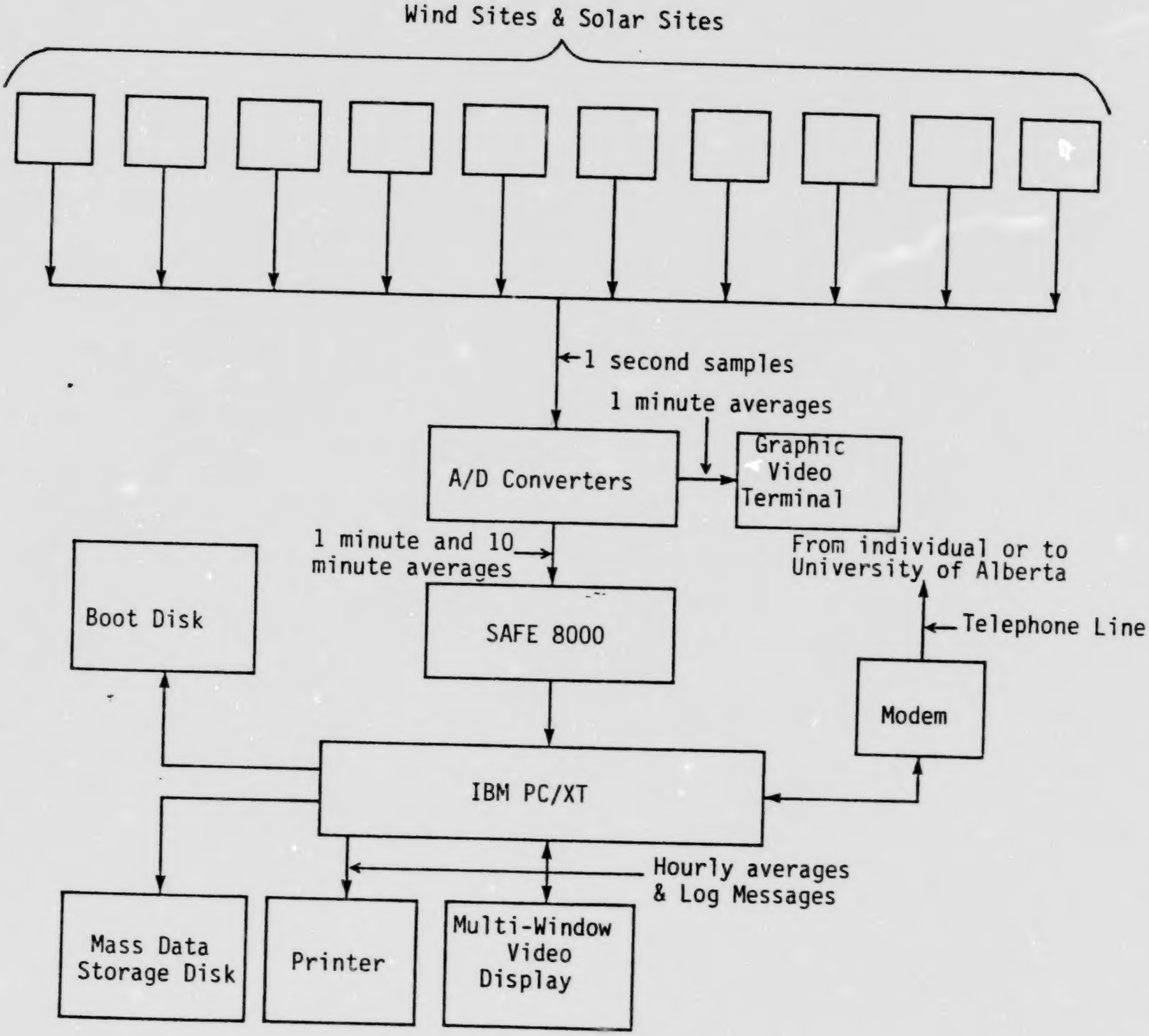
Both the SAFE and IBM system's hardware and software have been designed to allow for simple expansion. The IBM uses a UNIX based operating system such that it can operate in a multiuser/multitasking environment. As mentioned previously, a software package (written in C) was prepared in 1986/87 to facilitate the data collection, processing and transmission.

The on-site processing includes producing hourly averages of each sensor input and automatically producing daily summary reports of these values. The ten minute average data is stored on the hard disk (providing thirty days of backup storage), and once per day is transmitted via DATAPAC to the University of Alberta mainframe computer. The software and database is also designed such that an individual can dial into the system and determine the present operating status of each machine. The individual, through this menu driven software may also obtain a copy of any portion of the stored data or the hourly summaries for direct use with a graphics package such as Lotus 1-2-3. The operating system is also configured such that password protection allows only authorized personnel from performing modifications to the IBM or SAFE software. Because of the UNIX based operating system, all these tasks can be performed without interrupting the data monitoring process.

The monitoring system worked well throughout the summer and fall of 1986. In December, however, problems with the data acquisition system occurred when the Marapat electric turbine was being monitored. The system has been repaired, but the cause of the problem was never determined for certain. It is believed that the DC power supply system could not operate properly when it used the power generated by the Marapat unit. During these periods, the synchronization of the voltage and current cycles (power factor) was extremely poor and as such could have had the effect of causing rapid voltage fluctuations from the DC rectifier.

E) Monitoring and Analysis Procedure for the Development of Performance Curves

The monitoring procedures at the test site closely follow the Canadian Standards Association Performance Testing Standard (F417). Analog signals (weather monitoring package, current and voltage measurements) were sampled each second and averaged every ten minutes. Pulse signals (flow meters and future rotor speed sensors) were transmitted to accumulators which were read and reset every ten minutes. These ten-minute records were temporarily stored in a data base on a hard disk at the site. Each day at 1730 MST, the data records for the previous twenty-four hours were automatically transferred to the University of Alberta mainframe.


Wind Sites & Solar Sites
1 second samples
1 minute averages
A/D Converters
Graphic Video Terminal
1 minute and 10 minute averages
SAFE 8000
From individual or to University of Alberta
Telephone Line
Modem
Boot Disk
IBM PC/XT
Hourly averages & Log Messages
Mass Data Storage Disk
Printer
Multi-Window Video Display

DATA ACQUISITION SYSTEM

Figure 3

At the end of the test season, the data which had been received and stored at the University of Alberta were processed into performance curves for each unit. The analysis was performed using both a statistical package known as the Michigan Interactive Data Analysis System (MIDAS) on the mainframe computer (to eliminate data recorded during inoperative periods) and Lotus 1-2-3 on IBM personal computer (to visually fit a curve through the remaining data).

RESULTS

Preliminary performance curves were calculated and prepared for five of the seven wind turbines on the site. Three of the units were modified mid-season, and as such two performance curves were produced to illustrate the improvements made. Additional data analysis is being carried out to finalize the performance curves and calculate expected pumping yields for each of the mills at various sites in Alberta (which do not conform to a Rayleigh distribution) and for various mean monthly wind speeds based on a Rayleigh distribution. Also, the analysis for the TPS Industries Ltd. solar pumper is expected to be completed shortly.

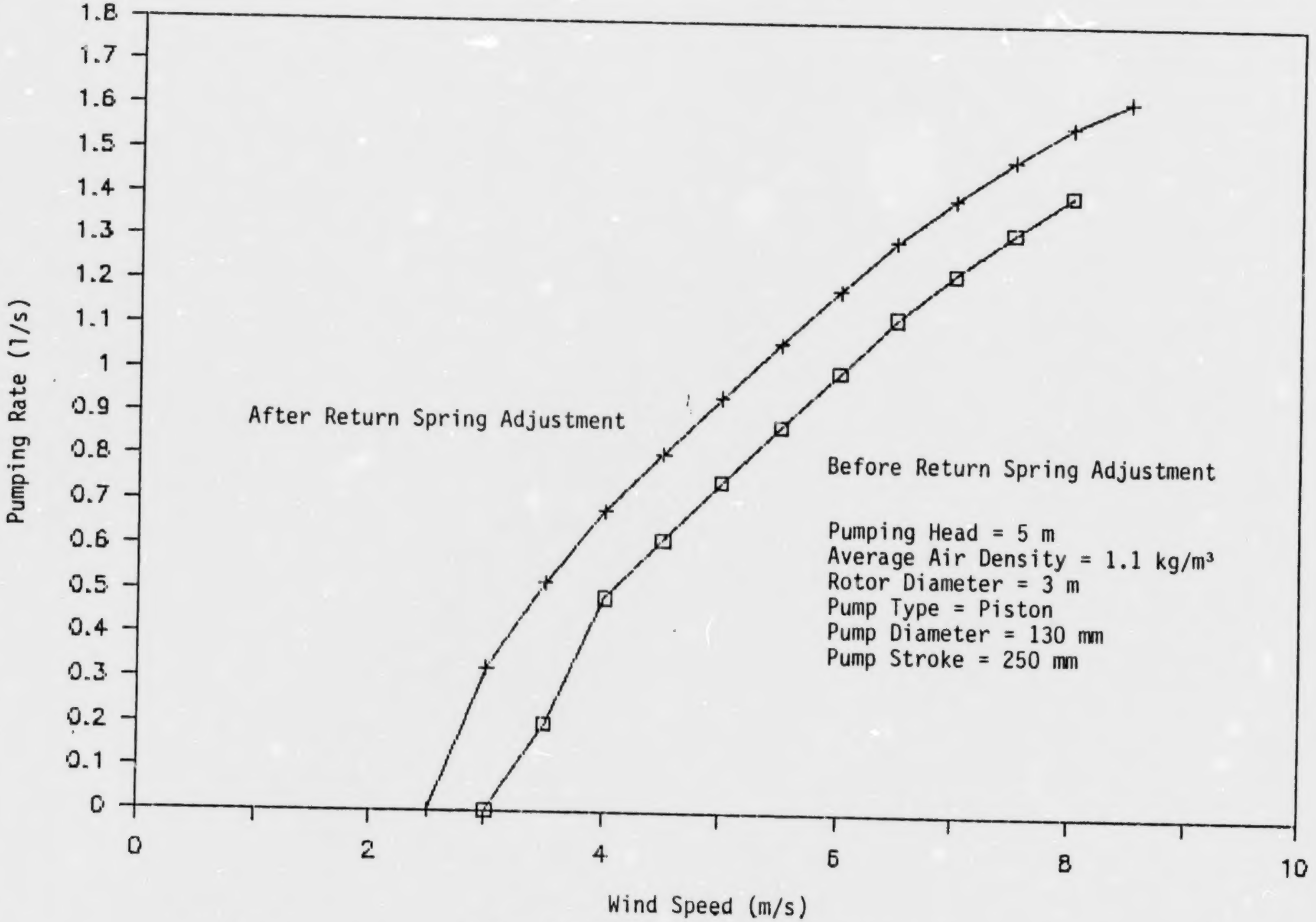
The operational performance of each of the mills is summarized as follows:

Wilks Cam - (Figure 4) Installed in late summer and operated nearly continuously until freeze-up. The unit was modified in mid-October by increasing the force developed by the springs which return the pump rod down into the well. This modification is shown to significantly improve the performance of the system throughout is operating range. Insufficient data was gathered to continue both curves above 9 m/s. Additional testing in 1987 will be required to complete the latest curve.

Chinook - (Figure 5) Installed winter of 1985 and has only operated intermittently since then, due to problems with the PVC pump system. The unit operated continuously during October of 1986, after the pump had been repaired. It can be seen that the peak performance after the pump repair increased by approximately 20%. This unit possessed the lowest cut-in wind speed (1.5 m/s) of all machines tested during 1986.

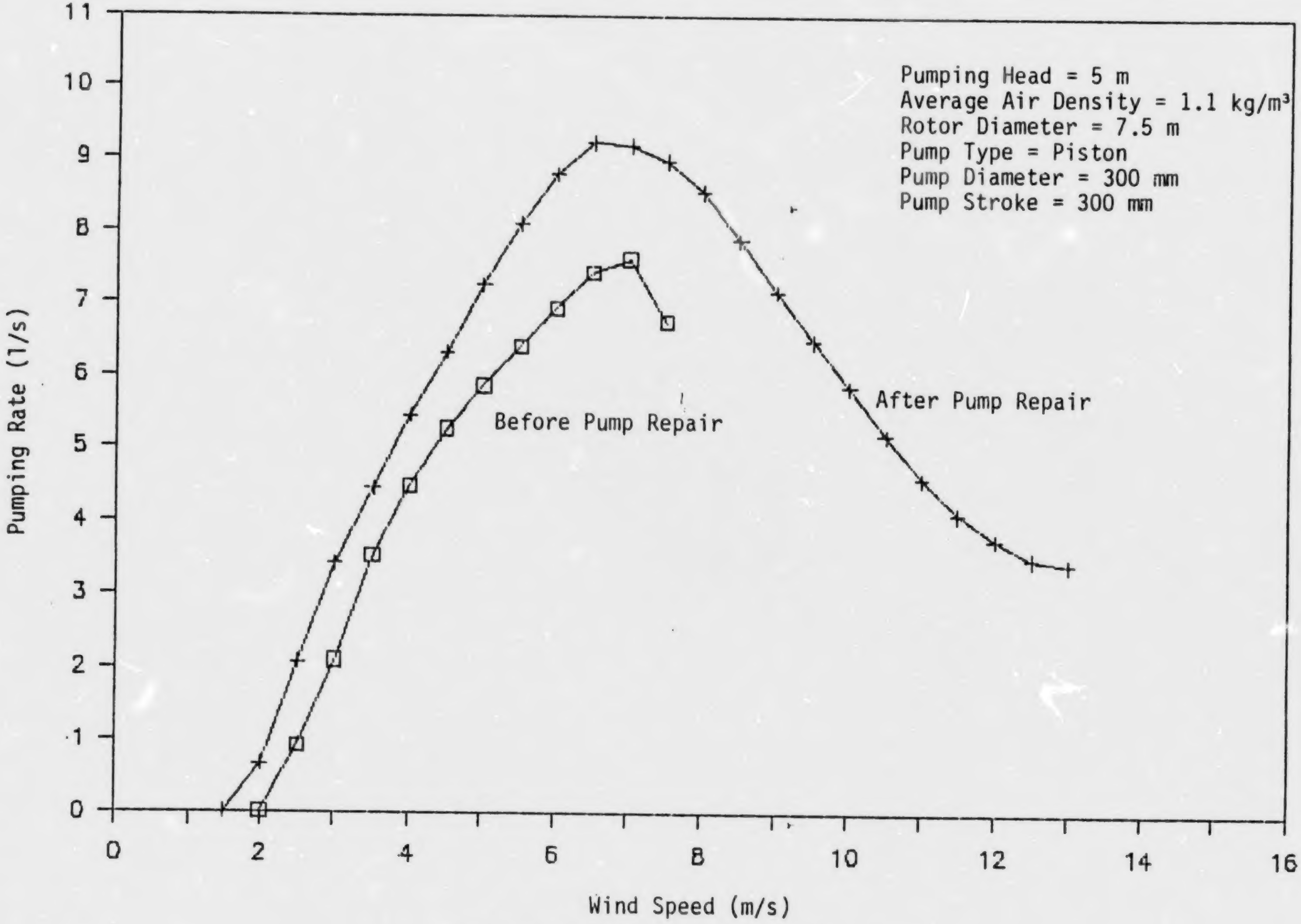
Bowjon Diaphragm - (Figure 6) Installed during the summer of 1985 and operated nearly continuously throughout the 1986 test season. This unit is configured to drive a diaphragm pump by an air compressor. It lost its rotor assembly in late fall of 1986. Replacement is expected by spring of 1987. Overall performance of this unit has not been as good as the previous Bowjon airlift system which used the same rotor and compressor.

Bowjon Bubbler - (Figure 7) As with the Bowjon 1 this unit was installed during the summer of 1985 and operated nearly continuously



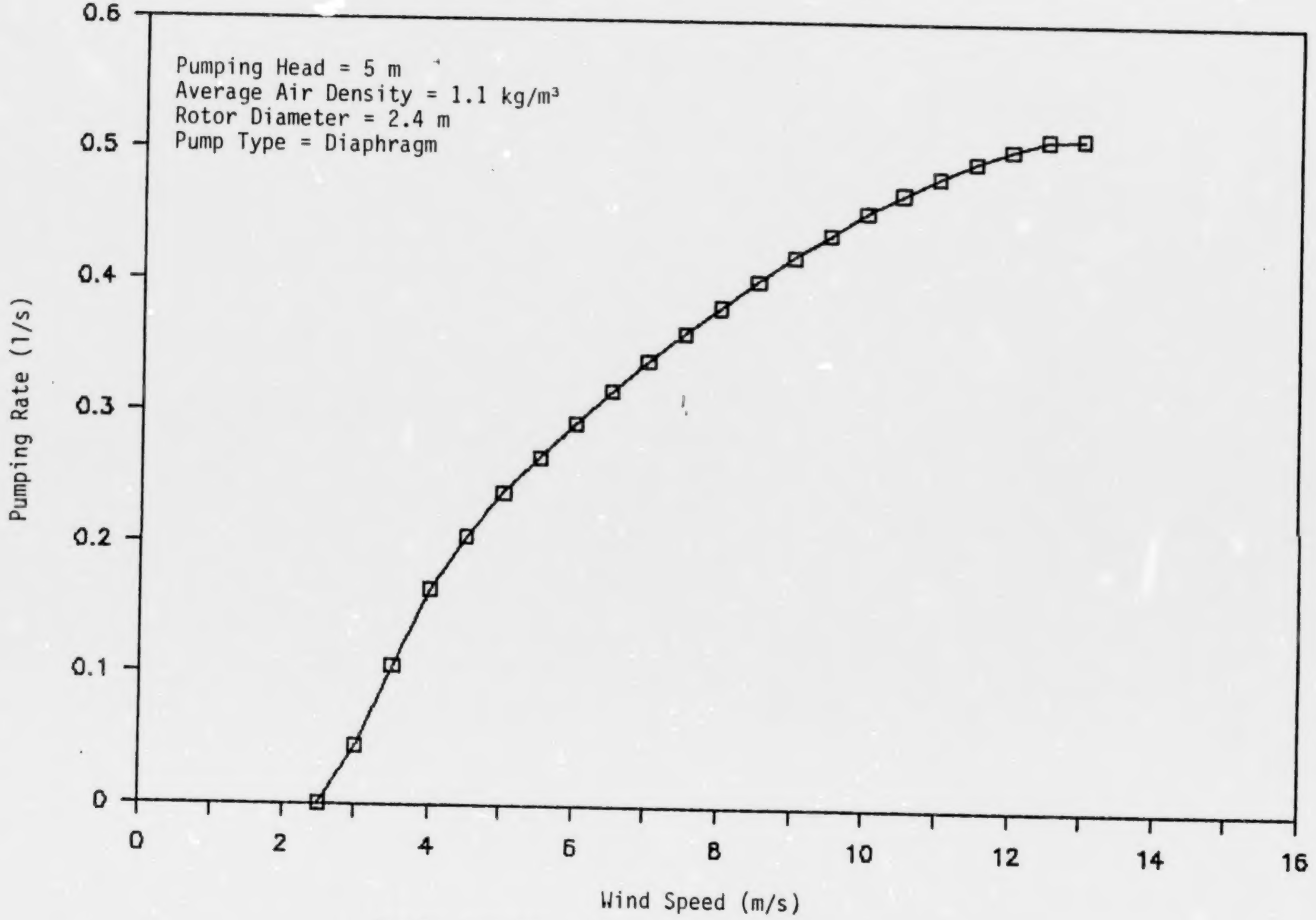
Wilks Cam #10 Performance, (Preliminary)

Figure 4



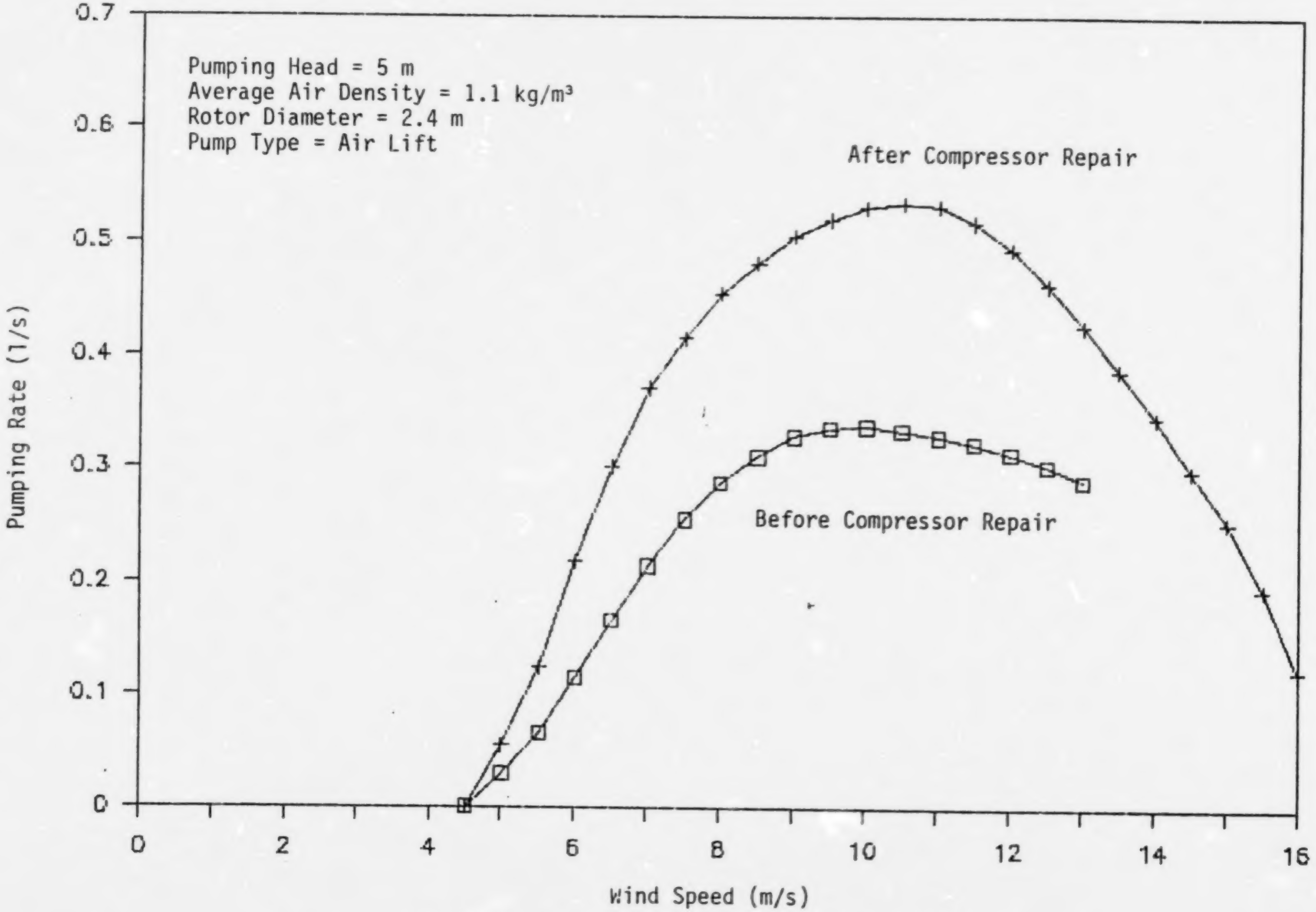
Chinook 7.5 Performance (Preliminary)

Figure 5



Bowjon Rancher - Diaphragm Performance (Preliminary)

Figure 6



Bowjon Rancher - Bubbler Performance (Preliminary)

Figure 7

throughout the 1986 test season. This unit is similar to the previously tested Bowjon airlift unit, but the compressor has been modified. After solving initial problems with the compressor, it was still not able to equal the performance of the previous unit. The 4.5 m/s cut-in wind speed was the highest of all machines tested during 1986.

Maverick Windquest - (Figure 8) Installed during the summer of 1986 and operated somewhat erratically until late fall when the drive cable broke. The unit also displayed problems with balancing of the swivel tower resulting in poor wind tracking and inconsistent performance. The unit has been dismantled and returned to the manufacturer's shop for repair and redesign.

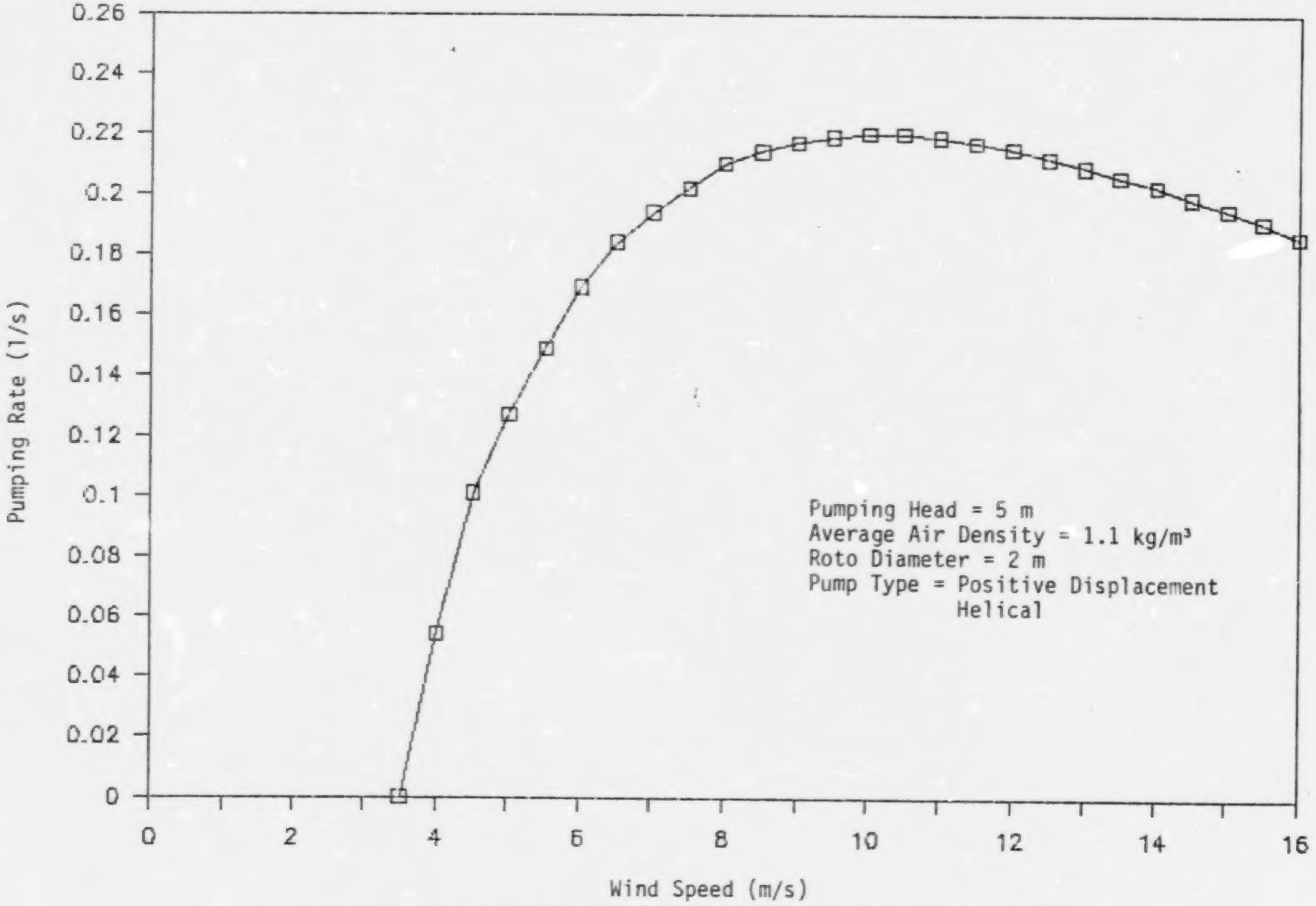
WP-20 - Originally installed in winter of 1985 using a mechanical drive system. After six days of operation the mechanical drive broke and no further testing was carried out until the drive was replaced with a hydraulic system in late fall of 1986. Simulated testing was carried out by measuring strokes of the hydraulic ram for one to two weeks. Problems with the ram has halted further testing until the spring. The switch from mechanical to hydraulic drive appears, however, to have excellent potential for this unit.

Nor'Wester - Installation was initiated in the summer of 1986 but is not yet complete. Testing of this machine is expected to commence by May of 1987.

Marapat (12.5 Kw) - Installation of this unit was initially completed in the fall of 1985. After twenty-four hours of operation this machine fell down due to high winds and inadequate support cable strength and anchors. Installation of a replacement unit took place in the spring of 1986 but operation of the unit did not begin until December 17, 1986 because of various problems with the alternator and blade systems. On December 25, 1986 the machine lost two of its three blades. Performance data (Figure 9) shows the machine has serious problems with quality and quantity of power output. The manufacturer is currently trying to determine what these problems are.

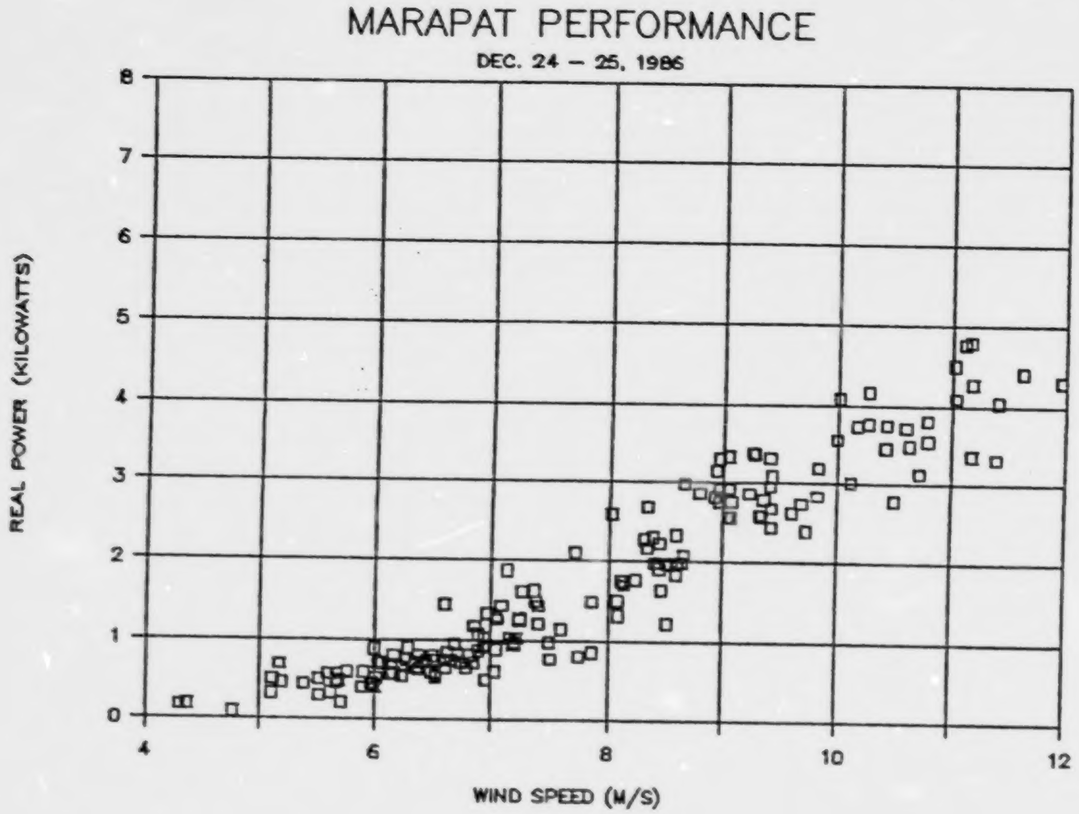
Cambrian & TPS Solar - The Cambrian has been operational at the site for approximately three years while the TPS unit was installed during the summer of 1986. Both systems have operated continuously since their installation with essentially zero down time. They are by far the most maintenance free systems on the site.

A common problem with almost all wind turbine manufacturers is finding or developing a suitable pump which will handle relatively large



Maverick Windquest Performance (Preliminary)

Figure 8


MARAPAT PERFORMANCE
DEC. 24 – 25, 1986
REAL POWER (KILOWATTS)
0
1
2
3
4
5
6
7
8
WIND SPEED (M/S)
4
6
8
10
12

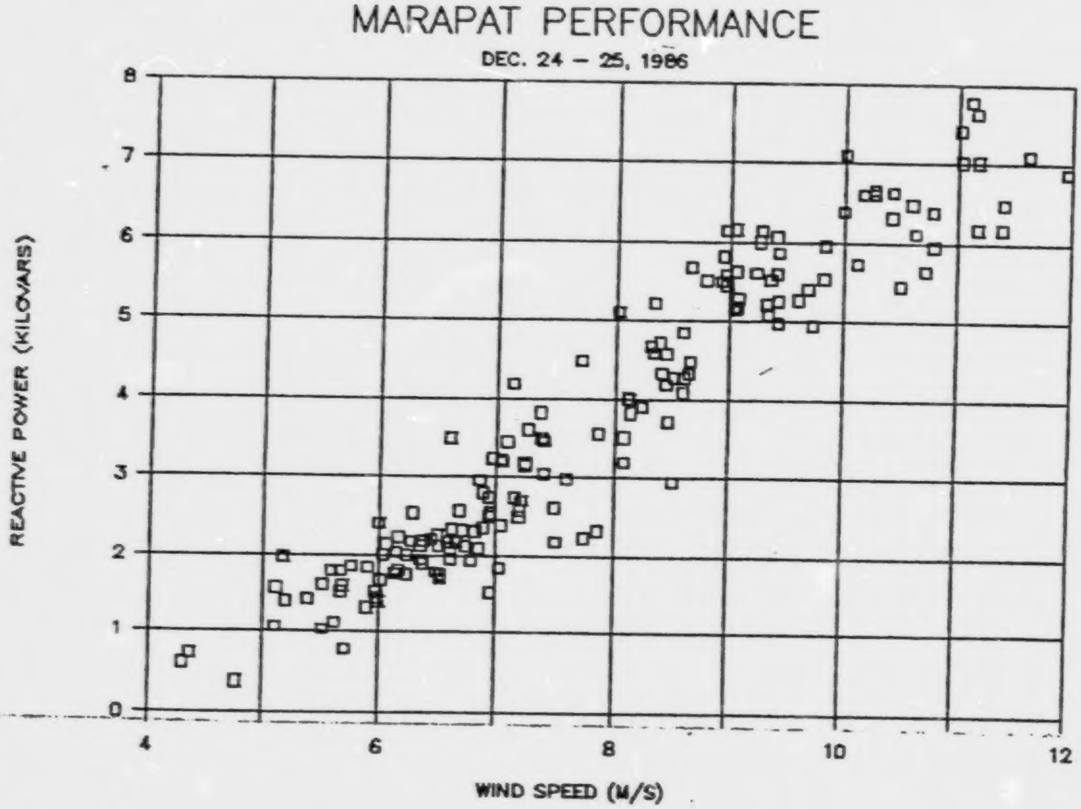

MARAPAT PERFORMANCE
DEC. 24 – 25, 1986
REACTIVE POWER (KILOVARS)
0
1
2
3
4
5
6
7
8
WIND SPEED (M/S)
4
6
8
10
12

Figure 9

volumes of water at shallow lifts. Overall system efficiency and mechanical integrity often suffers because of a poor match between the pump and the turbine system. Additional research on testing various pumping systems in relation to wind turbine performance is recommended.

FUTURE TESTING

Interest in the Lethbridge Wind Research Test Site by manufacturers and potential buyers continues to increase. During the summer of 1987, two additional water pumping wind turbines were installed at the site for testing. In addition, a one-day workshop was held to look at the potential market for wind and solar pumping systems. Participants from industry, various provincial and government representatives and manufacturers were present to discuss both the Canadian and international market potential.

In order to better test the water pumpers under more realistic conditions, a deep well simulator apparatus is currently being constructed which will allow pump testing of a turbine or solar system to depths of approximately 1000 feet. This will allow manufacturers to better match pump systems with their turbine or solar panels for the various depths potential clients might wish.

Operation of the Lethbridge Wind Research Test Site is expected to continue over the next two to three years with the inclusion of the deep well simulator apparatus. At the end of that time, a full evaluation of the testing facility will be carried out to determine its overall usefulness and future direction. If current interest in wind and solar water pumping systems continues to increase in both the Canadian and export markets, the future of the Lethbridge Wind Research Test Site looks bright.

WIND ELECTRIC WATER PUMPING - UPDATE

Jason Edworthy
Michael Bourns
Nor'wester Energy Systems Limited

Introduction

Our firm has been involved in water pumping systems based on wind electrical technology for about five years at the Lethbridge test site. We have been progressively working on systems using DC power without storage through to the present DC/AC system. Last year we described the present system in a paper which gave an overview of Canadian water pumping developments, and this year we are reporting on initial performance data for the present system.

The Maestro System

The Maestro system is based on a small independent, battery charging "mini-utility". It consists of a wind electric turbine, battery charging controller, battery bank, inverter and water pump. The turbine, battery bank and pump are sized specifically for the customer's requirements, and are typically available in turbine sizes ranging from 1 kW to 10 kW, and pump sizes from 1/4 hp to 12 hp.

The strength behind the concept lies in flexible siting, away from the water and closer to the wind resource, and also in the provision of standard 120/240 VAC energy for use with off the shelf pumps and other tools at the pump site.

The present system consists of a 24 volt Bergey 1000 wind turbine and EMS-4 energy management system controller, a 1500 watt Vanner inverter, 220 ampere hour battery bank, and a submersible 1/3 hp 120 VAC pump.

Experience With The System During the Past Year

As of this time last year, the system had been installed and operated for a very short duration, with only manually collected pumping data available.

The systems at the test site are shut down over winter due to freezing conditions. The system was placed into operation again in late April. However, we found that the 1/2 hp centrifugal pump we had placed with the system was placing much larger start up current surges on the inverter than it was theoretically supposed to. We spent considerable time in May and early June swapping in different systems to increase head on the pump for reduced start-up amperage, adding solenoids and reducers and even trading different pumps.

In mid-June we found that a submersible sump-type pump of 1/3 hp was working very well with the system. This was placed into operation. On the same day that we left Lethbridge an unfortunate occurrence at an adjacent site resulted in the data lines being cut to our location. This resulted in no data being available for our site during the initial operation of the final system for a period.

Several weeks later we were notified that the Maestro system was not and had not been pumping and apparently there was a problem with the inverter. The inverter was returned to the manufacturer under warranty, and was not again available until mid-August.

The system was once again placed into an operational state at that time, data collection began, and the system has apparently been operating correctly since then. We were able to receive the first data on performance late last week.

Performance

Due to the operating difficulties associated with the inverter failure in the spring, unfortunately performance figures are not available for the period at Lethbridge when it is most windy. The mid-August to late September period was not particularly windy at the site, with only a few days indicated as having peak wind speeds over 10 m/s, and many days with peaks less than 5 m/s.

We have only conducted a very preliminary analysis to date with the figures received. The theoretical constant pumping rate for the system is about 2 l/s (32 US GPM). The pump should deliver water at this rate constantly at operating voltages and current. Due to the design of the system, when available power cannot supply these from the battery, the system should shut down.

Apparently, this is what we are seeing in the present data. Few hourly averages show the full delivery rate, due to cycling of the system. The cycling is occurring because the wind speeds during this period are not ever high enough for a sufficient period of time to allow not only water delivery, but full charging of the battery bank. There is sufficient energy to drive the system for a period, with a small storage capability, but the system is not being cycled fully from discharge to full charge. Interestingly, peak pumping rates vary from 1.24 m/s to 2.07 m/s. This range may be due to the peak sampling method.

Figures 1 through 4 shown four typical 24 hour periods during which pumping occurred due to sufficient wind energy. Figure 1, August 20, shows a time lag between the occurrence of high winds and the peak pumping curve. This is an expected scenario when the batteries have been discharged well below operating thresholds.

Figures 2 through 4 show a closer relationship between wind speed and pumping rates, inidcating that the battery bank was charged nearly to operational state, but not sufficiently to operate without addition of the available wind energy.

All of these figures seem to indicate roughly that when the battery is in this condition, a requirement for winds of 5 m/s (11 mph) exists to bring the system into operation. This wind speed is equivalent to 50 watts power from the Bergey 1000 used in this installation.

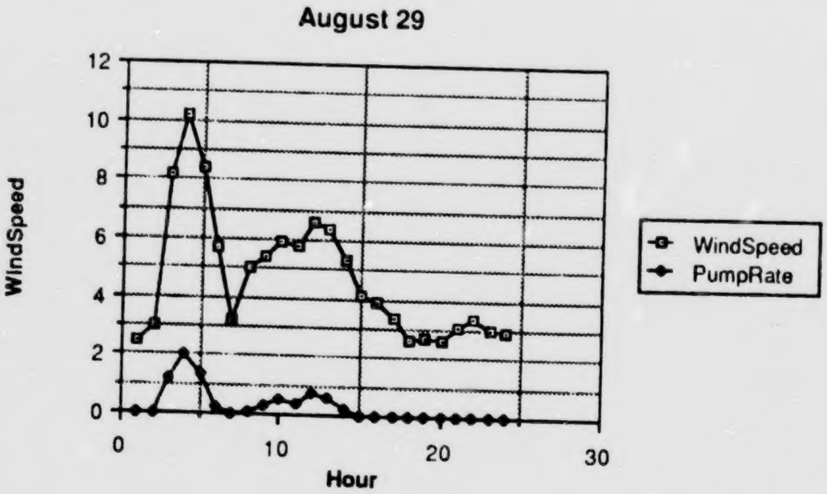
It will be interesting to examine time histories of the hours within these days to help determine the sequence of operations and to understand the lower than expected peak pumping rates. One of the difficulties for us and for the Lethbridge test site staff has been to anticipate which parameters to measure on this system to understand how it will perform, and how to express the performance, relative to the other systems installed at Lethbridge. These first data seem to indicate that it may be interesting to know how much time the inverter is operational, and how much time the windplant is delivering useful levels of power, accepted by the EMS-4. Because the system has storage capability, an inherent time lag exists in the system under higher wind conditions which make it difficult to correlate the pumping rate with the available wind, except as running means or averages over a particular time period.

Future Work

It is too early to draw conclusions with this limited data. We have indications that despite the system complexity, it does work and it does deliver water well, even at low wind speeds. We are concerned about reliability of such high-technology components as inverters, however these are improving all the time, and the present unit is apparently working satisfactorily.

We intend to continue monitoring the performance of the present system to determine optimum combinations of batteries, turbines and pumps. We intend to examine new DC pumps, including deep well systems, which will eliminate the inverter for appropriate situations, but retain the storage components of the system.

We also intend to examine new developments in three phase electric pumping, as have been approached by Whirlwind and Bergey Windpower over the past several years, and which are now looking promising.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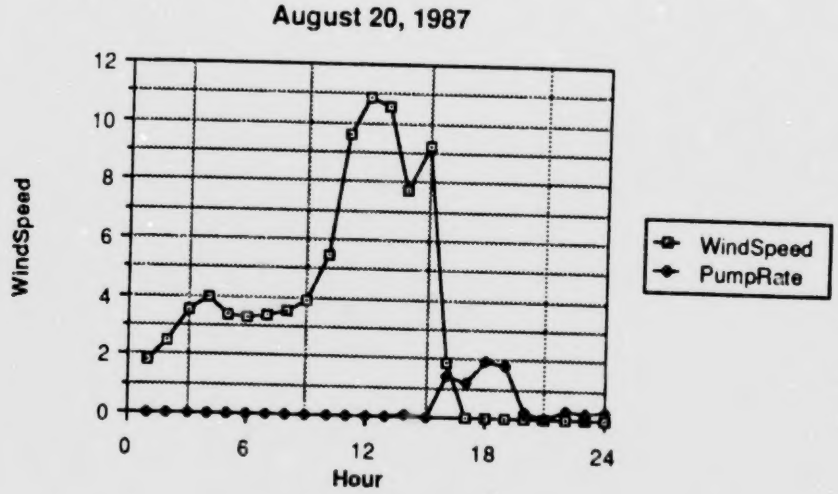
20
30
Hour
WindSpeed
PumpRate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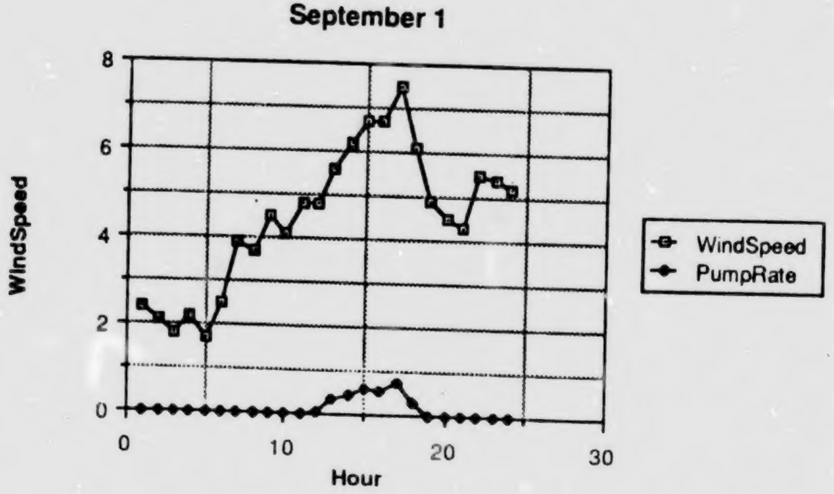
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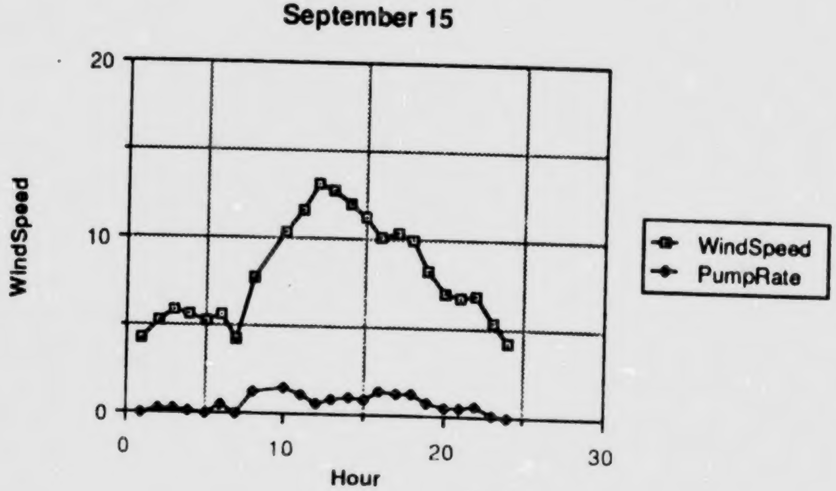
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Hour
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PumpRate

TECHNOLOGY DEVELOPMENTS II

PRINCE EDWARD ISLAND WIND FARM STUDY

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SUMMARY

A survey of potential sites for wind farms in Prince Edward Island was carried out and two representative sites selected for monitoring and assessment of wind energy resource. Both these sites have average windspeeds in the range of 6 m/s at 10 m elevation.

A steady decline in the cost of electrical energy purchased from New Brunswick during the period of this study has had a severe effect on the potential viability and attractiveness of a wind farm on Prince Edward Island. Over this period of time, the price paid by Maritime Electric Company Ltd. for electricity dropped from $70/MWh to $26/MWh.

The capital cost of developing a 2 MW wind farm was estimated at $2.6-3.7 million, and a 5 MW wind farm at $5.7-9.1 million. The low side capital costs reflect an untried but innovative vertical-axis machine from Adecon Energy Systems Ltd. of Toronto, the higher values were based on data provided by Vestas, an experienced Danish manufacturer.

With the lowest capital cost alternative, a publically-owned company would have to sell the power it generates at $79-88/MWh, while a large private company would require prices in the range of $86-95/MWh, to provide a return on investment of 12 percent.

Assuming that electricity prices will rise in the future to the $50/MWh range (which is still below the January 1985 peak of $70/MWh), a subsidy of 50-55 percent of the capital cost of a wind farm using the Adecon machine would be required to make the system economically viable.

This is beyond the financial capability and interests of the Province of Prince Edward Island at present. Although certain spinoff economic benefits would be felt from building and operating the projects in P.E.I., industry benefits from construction would be directed to the province of manufacture and most appropriate application and thus this geographic/political separation of economic benefits does not enhance the opportunity for support of the development of wind energy industry markets or wind farms in Canada.

If Canada is to be prepared to compete industrially for future markets in Canada then a limited market on a sufficient scale should be created to encourage industry and provide an opportunity for Canadian manufacturers to demonstrate their products. The Canadian wind turbine industry desperately needs a domestic market to provide a demand that would allow manufacturing on a reasonable scale and permit manufacturers to effectively demonstrate their products.

INTRODUCTION

Since 1973, when increases in oil prices caused the cost of electricity in Prince Edward Island to rise alarmingly, wind energy has been considered as one of the possible ways in which the province could reduce its dependancy on expensive imported fuel oil for electrical generation. In the past decade, several studies have concluded that there are certain conditions that must be met to justify the expense and risk of developing a major project to demonstrate wind energy technology on a large scale. In most instances, the discouragement is caused by a combination of high equipment cost and unproven reliability. Also, there have been no financial, investment, or industrial programs that have specifically directed commercial or market incentives to the wind energy sector of the renewable energy industry in Canada. As a result, at the end of a decade of research and development, there have been no major wind energy developments to date in Canada and there is no commercial industry able to supply cost effective and reliable machines. In contrast, there are major wind energy developments in several other parts of the world and many more in development.

During the last three years, there has been a dramatic improvement in the price, performance, and reliability of wind energy conversion system (WECS) equipment. This is particularly true for a number of machines manufactured in Denmark, the United States, Germany, and Holland. Today there are about 12,000 of these new WECS operating in wind farms and single machine applications around the world. Typically, the cost of energy from these machines has been reduced to less than 10¢/kW.hr and availabilities have increased to 95 percent and better. Maintenance requirements have been reduced to a few inspections and a lubricant change each year. Other countries including Canada have developed interesting prototype equipment that shows promise but that is not a stage of commercialization that allows a share in the rapidly expanding world market for machines.

The Prince Edward Island Energy Corporation (PEIEC), which has been directly involved in the wind energy investigations and demonstrations on P.E.I. for several years, commissioned this study jointly with the Federal Department of Energy, Mines, and Resources (EMR) to investigate the feasibility of a wind farm on P.E.I. The action was prompted by the realization that equipment had become more cost effective and reliable. The study commenced in late 1984 when avoided cost of electricity in P.E.I. reached 7¢/kW.hr.

This report details the findings of a study to investigate the feasibility of a wind farm on P.E.I. The study was funded equally by the PEIEC and EMR. The study was carried out over the period of January 1, 1985 until March 31, 1986.

SCOPE AND OBJECTIVES

The study was conducted to provide an up-to-date assessment of the current feasibility of developing a wind farm of appreciable dimensions in P.E.I. The study was to be constrained to an investigation of projects that were sufficiently large to have noticable impact on electrical energy supply in P.E.I. and yet not so large as to create risk to electrical grid stability or quality of power. To meet this objective, the study was designed to consider wind farms of 2, 5, and 10 mW total capacity. Wind farms of these sizes could be expected to contain from 4 to 200 commercially available machines with capacities ranging from 50 to 500 kW. The availability of sites of sufficient size to accommodate many machines was also considered in the establishment of capacity limit for the study.

Major considerations of the study were to examine site availability, wind resource, equipment availability, and to perform economic assessment of potential projects.

The survey of sites was to consider all of those areas with access to good roads, utility lines, and where suitable soils and clear land were available.

The wind resource at two selected sites was to be monitored and compared with historical data and with contemporaneous data available from other monitored sites in P.E.I.

Equipment available from suppliers and manufacturers in Canada and abroad was to be surveyed to identify systems which are potentially reliable and economic.

A brief economic assessment for all systems for which prices were available was to be made and an in-depth analysis made for the equipment that indicated most favourable cost, performance, and reliability.

BACKGROUND

Description

A wind farm consists of an array or group of WECS usually of the same type or model installed to supply electricity to utility grids. Today, the most common machines have ratings of 100 to 1000 kW.

The machines are usually installed in arrays that make best use of the land available and that allow capture of the maximum proportion of the wind available at the site. Careful attention is paid to selection of sites with a history of high average windspeeds. Often extensive wind monitoring and wind tunnel modeling of sites is carried out to identify the best locations on a site for placement of wind turbines.

In most instances, site improvements such as roadways and transmission line extensions must be made. Also environmental laws regarding drainage, wind erosion, and visual appearance must be adhered to. This requirement can pose difficult problems in arid and hilly regions.

Figure 1 illustrates a typical site plan for a multi-unit wind farm. A single-line electrical diagram is illustrated in Figure 2.

In most instances, all of the units or groups of the units in a wind farm installation are connected to a central computerized control system that supervises the machines and also collects and stores data for analysis of wind farm and individual machine's performance. Often the wind farm may be monitored remotely by telephone modems. A small control building incorporating space for storage of spares and maintenance equipment is usually built at the site.

Generally there is little difference between the characteristics of wind farms employing horizontal- or vertical-axis machines. At present, there are only a few farms using vertical-axis equipment.

WIND FARM SITING

Siting of wind farms is a process that involves the consideration of many factors. The number and necessary weighting of these factors is greatly influenced by the general characteristics of the area. Certainly the issues to consider for siting wind farms in a densely populated agricultural area like Prince Edward Island are vastly different than those encountered in the Mojave Desert or the San Gorgonio Pass in California. There are however some general areas that may be used almost universally to group the more specific factors. The areas that are most often used are:

(1) Wind Resource - topography, obstruction, windspeed, direction
(2) Land Condition - soils, drainage
(3) Land Availability - compatible with existing use
(4) Land Use - zoning, ordinances
(5) Servicing - utility, roads, communications
(6) Environment - visual, noise, study

SITE SELECTION

Survey of Sites

During the summer of 1984, the complete province of Prince Edward Island was surveyed for potential wind farm sites. The following factors were identified and considered in the assessment of sites:

(1) Exposure
(2) Site Size
(3) Accessibility to 3 Ø Utility Line
(4) Access to Roadways
(5) Property Ownership
(6) Land Use
(7) Soil Condition
(8) Visual Impact
(9) Availability of Windspeed Data

The survey was conducted by first identifying on 1:125,000 topographic contours map having forest cover information, regions and sites best meeting the criteria above.

Land Use Consideration

During the site survey activity, it became evident that virtually all of the interesting sites were located in regions of agricultural activity. Many are in valuable potato growing areas. Also, some of the sites were located on land owned by the provincial government and held for future agricultural development. Because of the interest that agencies and departments of government in Prince Edward Island have in agriculture activity, a meeting of interested parties was held to identify and discuss wind farming as it relates to agricultural land use. A meeting of representatives of the P.E.I. Department of Agriculture, the Department of Community Cultural Affairs, the Land Development Corporation, and the P.E.I. Energy Corporation was held. Coming from the meeting was a general recommendation that wind farms placed on land now in agricultural use would not be acceptable unless arrangements could be made to maintain the land in agricultural use with little loss of function.

An assessment of joint use concepts for many of the better sites indicates that there is good opportunity for its implementation. Discussion with farmers and property owners indicates that most are open to the prospect of leasing wind rights on their land to projects under acceptable financial and access arrangements.

WIND MONITORING

Two sites were selected from 18 preliminary sites for monitoring of windspeeds. The sites selected were in Sherbrooke near the south shore of Malpeque Bay and at Cable Head on the north shore of Prince Edward Island. Both sites were flat open terrain typical of potential P.E.I. wind farm sites. A low (5 m) hedge row was located 10 m to the north of the Sherbrooke site but was considered too low to seriously influence the lower anemometer.

Anemometers were placed at 10 m and 25 m elevation on "Tall Boy" towers. The anemometers used were Maximum Type 41.

Monitoring equipment used was Natural Power A50 Wind Compilator which measures windspeed and classifies measurements directly into bins of selectable width.

The instruments were installed in December 1984 and read on a monthly basis for the calendar year of 1985. Table 1 lists monthly average windspeeds obtained for each of the anemometers for the periods indicated. On several occasions, data was lost for short periods due to failure of anemometers. Numbers in parenthesis are estimates of windspeeds for lost data. These estimates are calculated and the average prediction based on contemporaneous monthly average windspeed from the data obtained at Summerside and Charlottetown airports, the AWTS, and the other site. The estimated value is used to calculate the annual average.

The anemometer failures are thought to be the result of ice accumulation and in one instance, failure in high winds of a U-bolt securing a tower extension which caused a tower top to fall to the ground.

Data obtained from the other sources for the same period are also listed in Table 1. Figure 4 illustrates the 10 m data in an annual distribution. Points of estimated data are in parenthesis. Figure 5 compares 10 m and 25 m data for two sites.

The results of the monitoring indicate that the windspeeds at sites selected to meet the criteria of good wind sites are significantly higher than the windspeed at the Summerside and Charlottetown airports. The annual average at selected sites is 15 percent higher at Sherbrooke and 16 percent higher at Cable Head. This result is about the same as that obtained in the wind resource assessment performed by the Institute of Man and Resources in 1983.

Although predictions of windspeed averages can be made with reasonable accuracy based upon contemporaneous observation from a nearby station, there is still a very significant uncertainty in predicting the windspeed of any future period. Natural variations in average windspeed on a monthly basis may deviate as much as 40 percent or more. Differences in annual averages from year to year at a specific location are often greater than 20 percent. These random variances can significantly influence the economic performance of a wind farm. Power outputs and energy production of a wind turbine rise rapidly with increasing windspeeds. For example, the annual energy produced by a typical wind turbine increases from 100,000 to 135,000 kWhr for an increase in annual average windspeed of 5.0 m/s to 5.8 m/s.

WIND FARM ECONOMICS

To examine wind farm economics, six European, one American, and two Canadian wind turbine manufacturers were asked to quote on the supply of equipment to build a 2, 5, and 10 MW wind farm. The European and Canadian manufacturers responded to the request. The response from Vestas Energy A/S of Lem, Denmark was the most complete in detail and seemed to be representative of wind turbine prices from other European manufacturers. Their quote was for a turn-key operation and was thus selected for analysis.

A wind turbine from Adecon Energy Systems Inc. of Toronto was chosen because of its innovative design and estimates low cost. Although there is little production and operational experience with the machine.

Although the original intention was to examine three wind farm sizes (2, 5, and 10 MW), the analysis has been restricted to the 2 and 5 MW sizes. A 10 MW wind farm at the sites selected would involve installation of a major transmission line and substation that could not be justified.

VESTAS ENERGY A/S

The Machine

The Vestas machine selected is a 90 kW horizontal-axis wind turbine. It is a 17 m diameter, three-bladed machine supported by a 23.4 m lattice tower. Vestas is one of the most experienced modern WECS manufacturers and has 390 WECS in service in Denmark and 1,837 WECS in California. There are 50 WECS in various other countries. Of these machines, 850 are the Type 17-90 kW. The machine is predicted to generate an annual output of 177 MW hours in a 6 m/s annual average windspeed

The Wind Farm

The wind turbines have been laid out for analysis purposes in a straight line running southwest to northeast roughly perpendicular to the prevailing wind. The machines would be placed on 50 m centers. A 2 MW farm would require 22 machines and a 5 MW farm would require 56 machines. In practice, depending on the suitability of land available, the machines could be aligned in 2 or more rows about 200 m apart.

Capital Cost

The capital cost for the two wind farm sizes are shown in Table 2. Cost quotes by Vestas are identified by values shown in both dollars and Kroners. Appropriate duty and federal sales tax have been applied to those items being brought in from Denmark.

A project management fee of 3 percent was charged against the project along with a 10 percent contingency to cover siting problems which may result in such as longer service roads and transmission lines. The Vestas price is for a turn-key project except for roads, foundations, and control building. Engineering required would be covered under the 3 percent fee.

The project was assumed to have an economic life of 20 years.

Revenue

Gross revenues have been calculated on the basis of manufacturer's specified output at 6 m/s average windspeeds. Outputs have been adjusted by an availability factor. The availability factor accounts for time when the wind is higher than that required to run the wind turbine but the wind turbine is not available because of servicing and/or mechanical repairs. Availability factors of 95 percent have been experienced with Vestas' wind turbines in California wind farms.

Various rates for electric power sales have been used in the economic analysis. In all cases, it was assumed that rates would rise 3.5 percent/year.

Operating Cost

Three categories of operating cost have been included in the economic evaluation:

(1) Land rental
(2) Property tax
(3) Service, maintenance, and supervision

ADECON ENERGY SYSTEMS

The Machine

The Adecon 19 m, 150 kW machine is a vertical-axis WECS with a two-bladed Darrieus-type rotor supported by a lattice work space frame. The rotor is 25.5 m high and has a diameter at the equator of 19 m. At 6 m/s average annual windspeed, the machine is expected to generate 278 MW hours.

The Wind Farm

The wind farm would be laid out similar to the Vestas configuration except that the machines would be placed on 75 m centers. The 2 MW farm would require 14 machines and the 5 MW farm, 34.

Capital Cost

The capital costs for the two wind farm sizes are shown in Table 3. Adecon supplied the costs for the wind turbines, foundations, and installation. The cost of local freight, control building, and wind farm control and monitoring system are estimated.

A project management and engineering fee of 5 percent was charged against the project. The higher fee (5 percent versus 3 percent for Vestas) reflects that Adecon would be supplying only wind turbines and not the rest of the equipment.

A 15 percent contingency has been added to the estimated project costs. This higher contingency reflects limited experience with these machines.

Revenue

Gross revenues have been calculated on the basis of projected machine outputs. Availability is assumed to be 95 percent, and various rates for electric power sales have been used in the economic analysis. While 95 percent availability would appear unreasonable for an untried machine, the more generous contingency and the expectation that the Adecon machine would be thoroughly tested before installation should justify the assumption.

Operating Cost

The three categories of operating cost have been handled in the same way as with the Vestas wind farms.

ECONOMIC ANALYSIS

The economic analysis has been carried out under each of the following general assumptions:

(a) that the wind farm would be owned by a public non-profit organization such as the P.E.I. Energy Corporation. Under this alternative, income taxes would not be paid and the accelerated Capital Cost Allowance on wind equipment would not have any economic effect.

(b) that the wind farm owner was a private company whose only business was the wind farm. The effect of the accelerated Capital Cost Allowance on wind equipment would be to defer tax payments into the future. The company would be eligible for the small business deduction which would reduce income taxes in some cases from 51 percent to 25 percent. No charges have been assessed against the economics for company formation etc.

(c) that the wind farm owner was a company with fairly substantial profits that could absorb the Capital Cost Allowance of the wind farm. The company's basic tax rate would be 51 percent.

(d) that the company was Maritime Electric Company Ltd.

(e) that there was mixed private and public operation.

In order to examine the economics, we must assume a selling price for the power produced by the wind farm. The recent decline in oil prices has substantially reduced Maritime Electric's cost of purchasing power. For example, in January 1985, the cost was $69.75/MWh while in May 1986, the cost was only $25.82/MWh.

In 1986, Maritime Electric Company Ltd. expects electricity rates to reach 615,000 MWh with a peak demand of 109 MW at 5:00 p.m. The 2 and 5 MW wind farms would generate approximately 3,900 MWh and 9,700 MW or 0.6 to 1.5 percent of projected sales of Maritime Electric Company Ltd. Because the wind farm is not capable of generating on demand, there is no capacity credit allowed.

Public Ownership

In Figure 6, the return on investment (ROI) versus selling price for electrical energy has been plotted for the 2 and 5 MW wind farms for both Vestas and Adecon. The ROI calculation assumes that the wind farm would be publically owned, thus, income taxes would have no effect. If we assume a minimum of 12 percent ROI, then rates paid for electricity produced would have to be:

2 MW Adecon Wind Farm	$88/MWh *
5 MW Adecon Wind Farm	$79/MWh *
2 MW Vestas Wind Farm	$120/MW *
5 MW Vestas Wind Farm	$118/MW *

* These represent 1986 prices and would be expected to escalate at 3.5 percent per year.

To examine the effect of capital cost on the potential returns that could be earned, the ROI has been held constant at 12 percent and a capital cost calculated for each electricity selling price. These results plottedin Figure 7. While there is some difference between the Adecon and Vestas data for a 2 MW farm, it is similar enough to conclude the following for a 12 percent ROI:

Electricity Selling Price ($/MWh)	Capital Cost $(millions)
50	1.2
70	1.9
90	2.6
110	3.3

Private Ownership

The question of public or private ownership is preferred is beyond the scope of this study. However, we can look at the effect of ownership on ROI.

In Figure 8, the ROI versus electricity selling price in a public corporation, a small wind farm company, and a large company is plotted for a 5 MW Adecon wind farm was used.

Ownership	Electricity Selling Price ($/MWh) (to achieve 12 percent ROI)
Public Corporation	$79
Large Private Corporation	$86
Small Wind Farm Corporation	$98

With a large private corporation as owner, the accelerated CCA produces favourable tax reductions during the first three years (tax reductions effected for the company have been credited to this project analysis). However, after three years, income for the remaining seventeen years would be taxed at 51 percent.

In the case of the Small Wind Farm Corporation, the company has insufficient earnings during the first years to absorb all of the CCA. The unused CCA could then be carried forward to eliminate taxes in succeeding years. When the deterred CCAs are used up, the company would then be taxed in the normal manner.

In Figure 9, the effect of changing the average wind velocity for a site is shown. In this example, a Private Wind Farm Corporation is the owner. At 6 m/s, a selling price of $105/MWh is required to yield a 12 percent return on investment while at 7 m/s, a selling price of $76/MWh would achieve the required return.

Maritime Electric Company Ltd

An analysis of the economic data was carried out using the utilities' analytic technique of levelized expenses. The basis for these were the December 31, 1984 data supplied by Maritime Electric Company Ltd. The levelized annual fixed charge rate was 19.21 percent of capital after allowing for an increase in Provincial Income Tax (10 to 15 percent), the rate becomes 20.25 percent. However, wind farm equipment will be eligible for a 3-year rapid write-off which will reduce the annual fixed rate charge to 14.73 percent (this includes the increased Provincial tax rate). Annual operating costs are levelized by discounting the annual costs back to Year 1 and determining the annual rate at which they will be uniformly amortizied over the life of the investment.

Taking the 2 MW Adecon Wind Farm as an example:

Capital Cost	$2,583,000
Levelized Fixed Charge Rate	$14,737
Levelized Annual Operating Cost	$76,000
Annual Energy Production	3,892 MWh

$$\text{Fixed Charge/MWh} = \frac{0.1473 \text{ X } \$2,583,000}{3892 \text{ MWh}} = \$98$$

$$\text{Operating Cost} = \frac{\$76,000}{3892 \text{ MWh}} = \$20$$

Total Levelized Cost = $119/MWh

	Fixed	+	Operating	=	Total
2 MW Adecon Wind Farm	$ 98	+	$20	=	$119/MWh
5 MW Adecon Wind Farm	$ 88	+	$18	=	$106/MWh
2 MW Vestas Wind Farm	$140	+	$24	=	$164/MWh
5 MW Vestas Wind Farm	$136	+	$23	=	$159/MWh

Clearly the two most important factors are the Capital Cost and the Wind Farm Electrical Output. A 10 percent change in Capital Cost or Electrical Output is equal to a 50 percent change in Operating Cost.

Mixed Private and Public Operation

Perhaps the best operating and ownership scheme for a wind farm would be where the WECS manufacturer built the equipment, installed it, and installed the rest of the wind farm equipment. The manufacturer would own and operate the farm for the first three years. Then the wind farm would be leased to a public operating body such as the PEI Energy Corporation. It could also be leased to Maritime Electric Company Ltd. (Most of the income taxes collected are returned to the Provincial Government.) The major advantages of such a scheme are:

(1) Responsibility for bringing the wind farm in at an agreed price would be the responsibility of the manufacturer.

(2) The manufacturer would be responsible for the first three years operation, thus enabling the lessor the opportunity to confirm that the electrical output from the farm is living up to expectations and that operating costs are within budget.

Using the cost for a 2 MW Adecon Wind Farm and assuming that Adecon was a large profitable company, the economics of such an arrangement were examined.

The analysis assumes the manufacturer would build the farm for $2,583,000 and operate it for three years. In the fourth year, the public company takes over operation of the farm. The public company pays the manufacturer a take-over fee of $250,000 and leases the farm for an annual payment of 252,000 ($1,900,000 at 12 percent for twenty years). In the twentieth year, the remainder of original cost is due and payable ($683,000). For the remaining seven years of the thirty-year economic life of the wind farm, the public company owns the farm outright and continues to operate it.

At an $70/MWh selling price with a modest 3.5 percent annual increase, the manufacturer (exclusive of any profit built into the wind farm equipment) would earn an after-tax return on investment of 8 to 9 percent while the public company would earn 15 to 20 percent. Increases in the take-over fee has a major effect on the public company return on investment, but a relatively minor effect on the private company as a result of taxes.

Conclusions

At 1986 selling prices for electricity at $25 to $28/MWh, none of the ownership alternatives are attractive for the 2 and 5 MW Wind Farms. A private company would be expected to earn an after-tax return on investment of 10 to 12 percent on electricity sales in the range of $80 to $90/MWh.

In February 1985, when the electricity selling price (avoided cost) was $70/MWh with normal increases of 3.5 to 5.0 percent per year. A wind farm was getting very close to an economical viability. However, international oil prices have since declined dramatically. This decline was particularily acute from January 1986 to June 1986 when they declined from 31.83 to 14.82 C$/barrel. Over the corresponding period, the purchase price of electricity from New Brunswick declined from $51.37 to $22.39/MWh. While it would appear reasonable that these costs for electricity will rebound, it would be economically and politically difficult to justify the investment in front of the Public Utilities Commission. A significant capital grant would be necessary to put the investment into a favourable light.

CONCLUSION

Prince Edward Island, because of its dependance for electrical supply through purchases of electricity from neighboring New Brunswick or by generation with a small and relatively low efficiency oil-fired thermal plant, is one of the more attractive locations in Canada for development of wind energy projects to produce electricity. During the period from the commencement of oil supply and price disruption in 1973 until oil prices declined rapidly, wind turbine reliability and performance had improved steadily to the point where economically attractive wind farm projects were on the immediate horizon. Had the price of oil remained at its higher levels or continued to increase, there is little doubt that wind farms in Prince Edward Island would be a reality before 1990. The realization of wind farms in this period now will depend greatly on a quick reverse in the downward trend of oil prices and upon government and utility policy and attitudes towards development and investment in wind energy as an alternative electrical energy supply.

Although Prince Edward Island seems to have many open and exposed coastal locations where wind farms could be located, the survey of potential sites has indicated that only a few locations are practical for wind farms having capacities of several megaWatts. The unavailability of three-phase distribution lines of adequate capacity and the density and distribution of residential and farm developments makes many sites unattractive. Inland sites are unattractive because of the high levels of forest cover and knowledge that average annual windspeeds are generally less than 5 m/s. There are no high ridges or hills that are cleared and considered good sites. Of the sites identified and inspected, the region of Sherbrooke on the south of Malpeque Bay was considered as the prime location. Discussion with property owners indicates that land leases could be arranged thus enabling low-cost acquisition of necessary space. In most instances, existing agricultural activity could continue.

Wind turbines of satisfactory reliability and performance are now available for wind farm development. Many machines have warranties of five years and have been in operation in California wind farms for upwards of three years. Experience with these machines has led to further improvements in operational characteristics and reliability. Costs are also decreasing as improvements and refinements in components and design are incorporated in the manufacture of machines. Reduction of tax and investor incentive credits has also caused manufacturers to become highly competitive in price and warranty quotes for equipment.

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TABLE 1

Prince Edward Island Windspeeds

	Sherbrooke		Cable Head		CFB Summerside	Charlottetown Airport	Atlantic Wind Test Site
	10 m	25 m	10 m	25 m	10 m	10 m	10 m
January	7.0	7.4	7.2	8.6	6.38	5.22	8.7
February	5.6	6.1	5.9	7.1	5.08	4.61	6.2
March	5.7	(6.5)	6.1	6.7	6.28	5.22	6.7
April	6.2	7.0	5.5	6.5	5.86	4.75	5.9
May	5.5	6.1	4.0	4.9	5.14	4.33	5.0
June	4.7	5.1	4.6	5.7	5.31	4.86	5.7
July	4.8	5.4	4.4	4.9	4.97	4.55	5.4
August	4.3	5.1	4.7	5.8	3.03	3.27	4.4
September	6.7	6.6	5.8	7.3	4.11	3.55	5.6
October	7.4	8.2	6.5	7.8	5.88	4.61	8.1
November	6.9	7.9	7.7	8.1	5.36	4.83	7.6
December	8.3	8.8	8.0	(8.7)	5.77	4.53	8.4
Average	6.0	6.7	5.8	6.8	5.26	4.53	6.47
Historical Averages:							
1985	6.0	6.7	5.8	6.8	5.26	4.53	6.47
1984	-	-	-	-	5.85	5.15	5.43
1983	-	-	-	-	5.71	-	5.89
*1966-76	-	-	-	-	5.42	-	-
**1955-72	-	-	-	-	6.44	5.36	-

* Prince Edward Island, Institute of Man and Resources Study

** Canadian Normals, Volume 3, Wind, 1955-1972.

TABLE 2.

Wind Farm Installation Costs : Vestas WECS

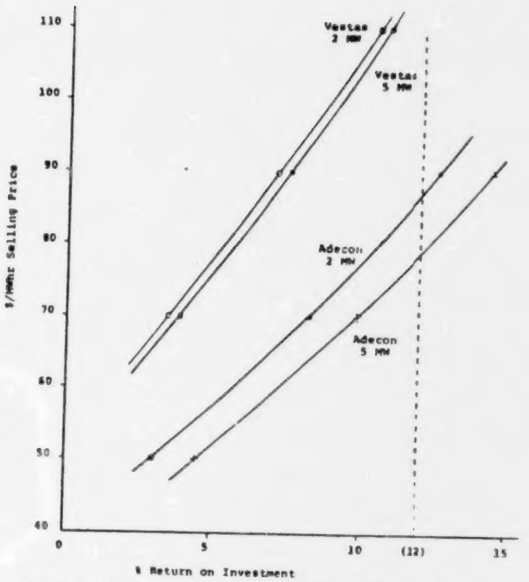
$Can = DK 5.96

		2 MW WIND FARM			5 MW WIND FARM	
No. of Machines		22			56	
		DK	Can $		DKK	Can $
Wind Turb. Gen.	(405009 DKK ea.)	8910	1495		22680	3805
Towers	(50010 DKK ea.)	1100	185		2800	470
Transformers		266	45		625	105
Misc.	(Tools)	52	9		104	17
Ocean Frt.		310	52		808	136
Duty @ 9.9% on above			177			449
Cable		338	57		859	144
Busbar and Fuses		259	43		611	103
Duty @11.3% on above			11			28
Data storage comp.		350	59		410	69
Duty @ 3.9% on above			5			5
F.S.T. 12% on above			256			640
"O/Land Frt.	($600/cont.)		8			20
Misc. Frt.	($4600/cont.cable etc.)		9			12
Transport Ins.(1%)			19			48
Foundations		1650	277		4200	705
Crane Rental		334	56		617	104
Supervision		455	76		665	112
Local Labour		1395	234		3522	591
Control Bldg.	(7.5mx9m @ $430/m)		29			29
Transmission Lines	($35000/km 1.1km)		39	(2.8 km)		98
Access Roads	($90/m+$10k 1.1km)		109	(2.8 km)		262
Primary Metering			13			13
Project Mgt.	(3% of above costs)		98			239
Transformer (69kV)						100
Sub-Total			3360			8302
10% Contingency			336			830
TOTAL COST			3696			9133

TABLE 3.

Wind Farm Installation Costs: Adecon WECS

		2 MW WIND FARM		5 MW WIND FARM
No. of Machines		14		34
		$ CAN.	in (000)'s	$ CAN.
Wind Turb. Gen.	($100k ea.FOB PEI)	1400	($87.9k ea.FOB PEI)	2988
Fed. Sales Tax	(12%)	168		359
Local Frt.	($400ea.)	6		14
Foundation	($6000ea.)	84		204
W.E.C.S. Install.	($6000ea.)	84		204
Feed VAWT/T'formers	(5 VAWT @ $30200ea.)	60		181
	(4 VAWT @ $21400ea.)	21		21
U/Gr'd. Primary	($5900ea.)	18		41
Transformer F'dation	($1200ea.)	4		8
Transformers	($20500 Installed)	62		144
Control Bldg.	(7.5mx9m @ $430/m)	29		29
Trans. Line	($35000/km 1.05km)	37	(2.55km)	89
Roads	($90/m+$10k 1.05km)	105	(2.55km)	240
Data Computer		50		60
Primary Metering		13		13
Transformer (69 kV)				100
Project Mgt.& Eng.	(5% of above costs)	107		235
SUB-TOTAL		2248		4930
15% Contingency		337		739
TOTAL COST		2585		5669



NOTE: Maritime Electric Cost January 1985 was $69.75/MWhr
Maritime Electric Cost April 1986 was $28.43/MWhr

FIGURE 6. Selling Price Versus Return on Investment
(Public Ownership No Income Taxes)

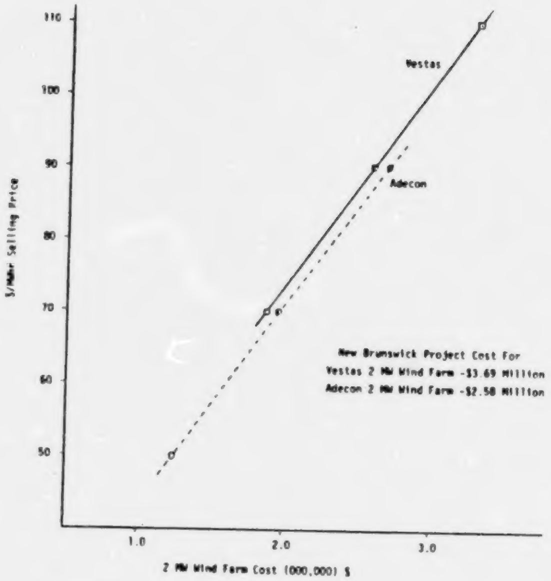
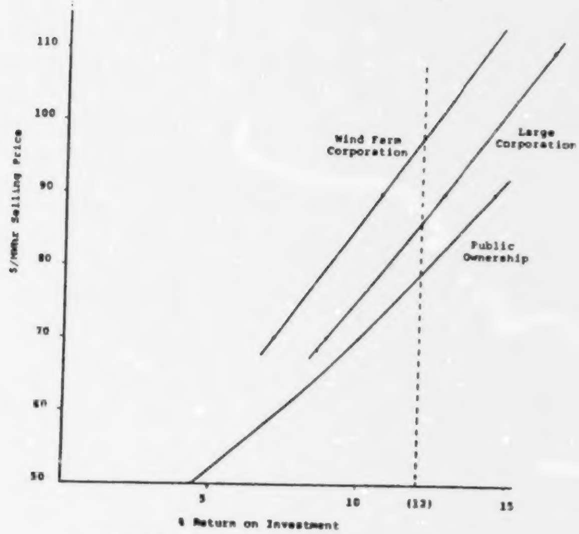
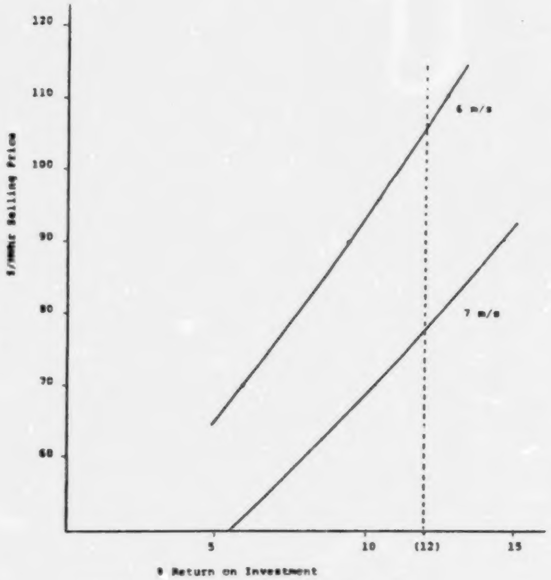


FIGURE 7. Wind Farm Cost Versus Electricity Selling Price
To Yield 12 Percent Return on Investment
(Public Ownership: No Income Taxes)



* Wind Farm is the Corporation's Only Business

FIGURE 8. Selling Price Versus Return on Investment
5 MW Adecon Wind Farm
Large Corporation, Wind Farm Corporation*
Public Ownership



* Wind Farm is the Corporation's Only Business

FIGURE 9. Selling Price Versus Return on Investment
2 MW Adecon Wind Farm (Wind Farm Corporation)*
6 m/s and 7 m/s Average Windspeed

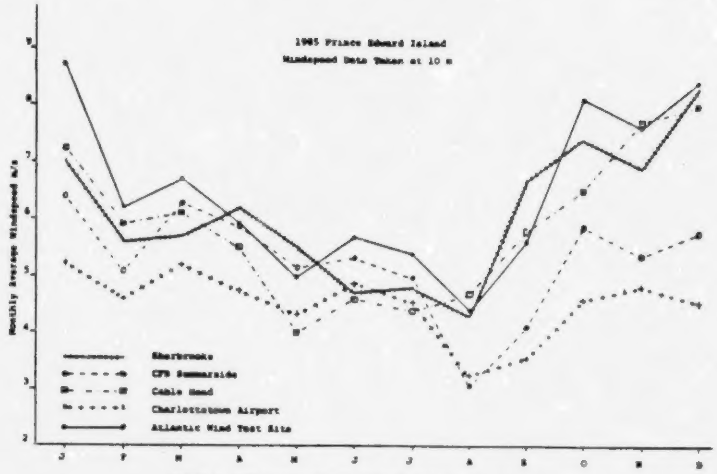


FIGURE 4. 1985 Monthly Average Wind Speeds (10 m Elevation)

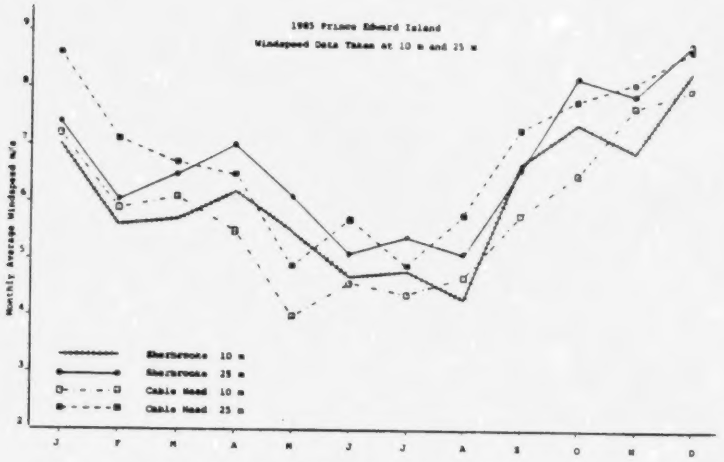


FIGURE 5. 10 m and 25 m Wind Speeds at Monitoring Sites.

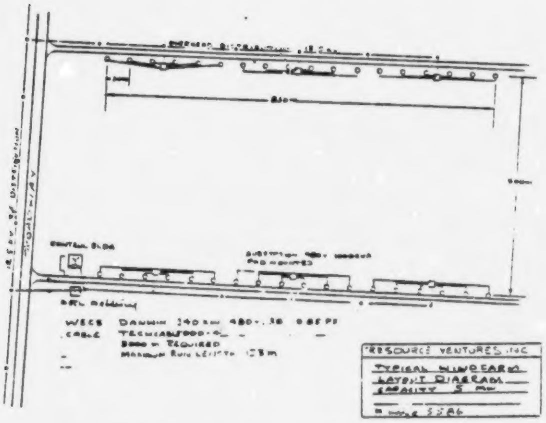

CONTROL BLDG
WECS
CABLE
RESOURCE VENTURES INC
TYPICAL WINDFARM
LAYOUT DIAGRAM
CAPACITY 5 MW

FIGURE 1 Typical Wind Farm Layout

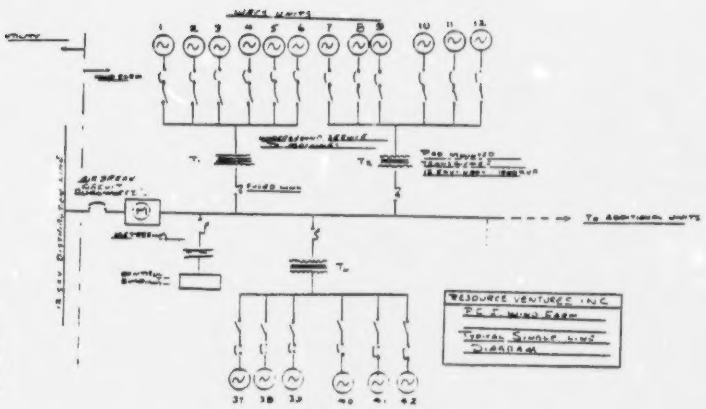

WECS UNITS
1
2
3
4
5
6
7
8
9
10
11
12
T1
T2
T4
TO ADDITIONAL UNITS
37
38
39
40
41
42
RESOURCE VENTURES INC
P.E.I. WIND FARM
TYPICAL SINGLE LINE
DIAGRAM

FIGURE 2. Typical Wind Farm Electrical Diagram.

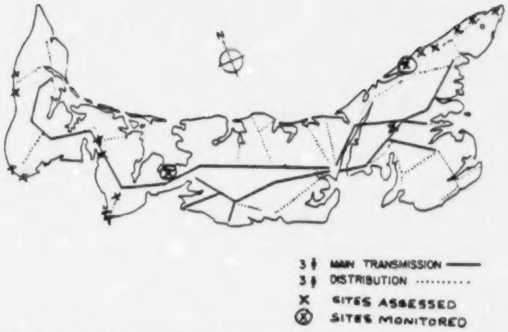

N
3 ϕ MAIN TRANSMISSION
3 ϕ DISTRIBUTION
X SITES ASSESSED
⊗ SITES MONITORED

FIGURE 3. Map of Prince Edward Island Illustrating Sites Selected and Assessed for Wind Farm Development.

DARRIEUS STRUT MODIFICATIONS

David Salt
Indal Technologies Inc.

THE PROGRAM

In 1982 Indal Technologies began a program to create a commercial VAWT in the 500 kW size. One of the first steps was to produce a small number of machines and operate these for several years to prove the design and validate our computer model.

One of the two machines tested was the 500 kW VAWT machine located at the Atlantic Wind Test Site. This fully instrumented machine was purchased by the National Research Council and has been operated at the Atlantic Wind Test Site since September of 1984. Since the closing of the Energy Division of the National Research Council (NRC) the Department of Energy, Mines and Resources (EMR) has assumed the NRC's role in the program.

Significant achievements to date are one full year of reliable operation and the generation of 83 Mwh - 30% of rated capacity - in a one month operating period.

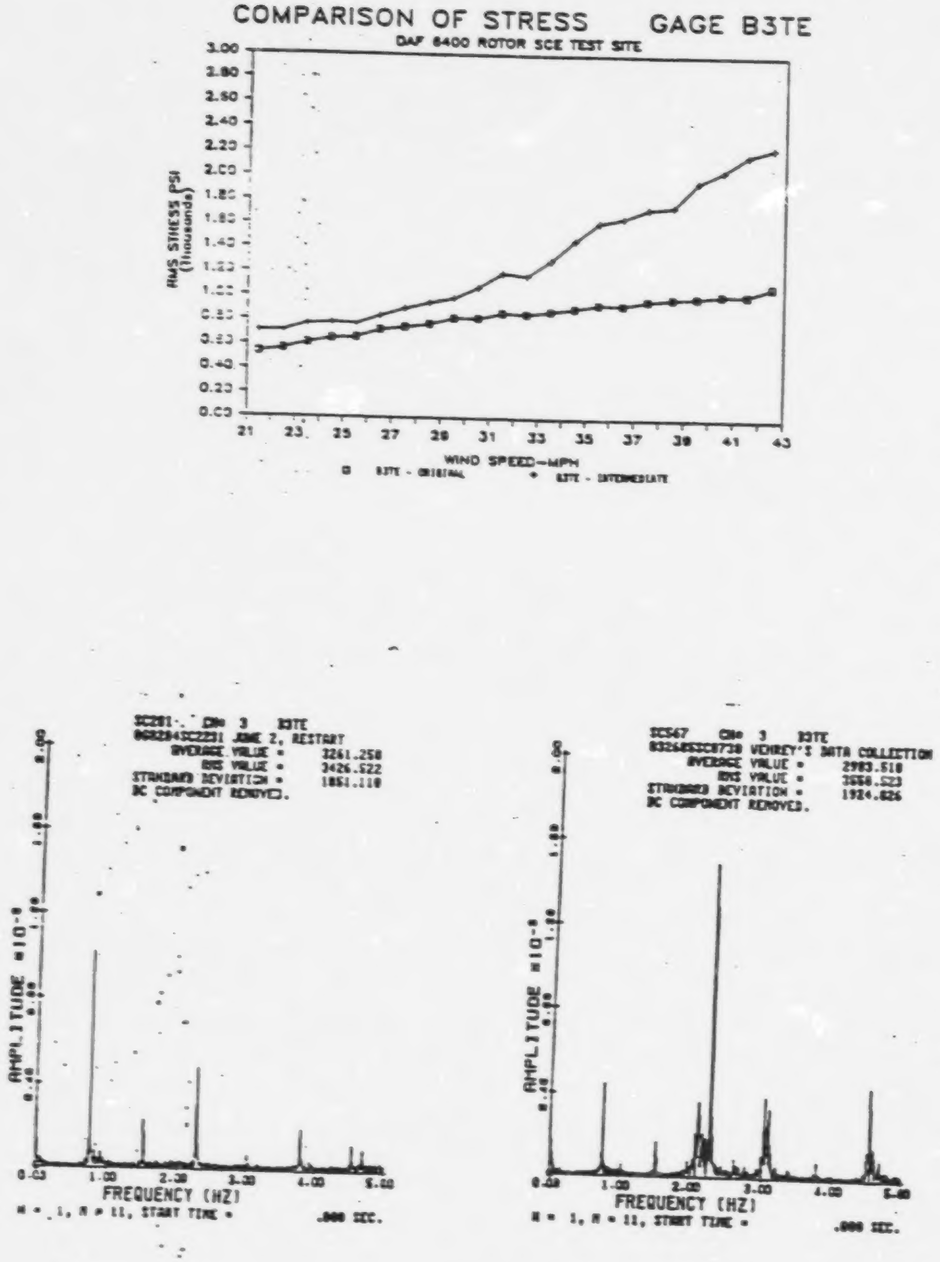
In November 1985, fatigue failure occurred at the attachment point of the upper strut and the blade. This joint is shown in this view. The failure resulted from local fatigue damage and was reported in NRC Structure Laboratory Report LTR-ST-1582.

The original rotor was designed for a 20 year life and fatigue samples simulating blade joints and splices confirmed that this aim would be met. Our only difficulty was with the strut damper system which worked well but had an unacceptable failure rate. This led us to lockup the struts to simplify the design and enhance reliability of our "Intermediate Configuration".

Locking up the struts led to a reduction in strut compliance but this was compensated for by reballasting the blades. We did this by filling a second gallery in the blade extrusion with glass beads - a weight increase of 400 lb per blade.

Unfortunately the reballasted configuration exceeded the stress levels incorporated in the original design which had been confirmed in both computer modeling and field testing in PEI and at SCE (California). Thus, while the stress levels in the Intermediate Configuration were the same as those in the original up to wind speeds of 30 mph (specifically at the B-3 location), above 30 mph they were almost doubled at rated power, with an attendant increase in fatigue.

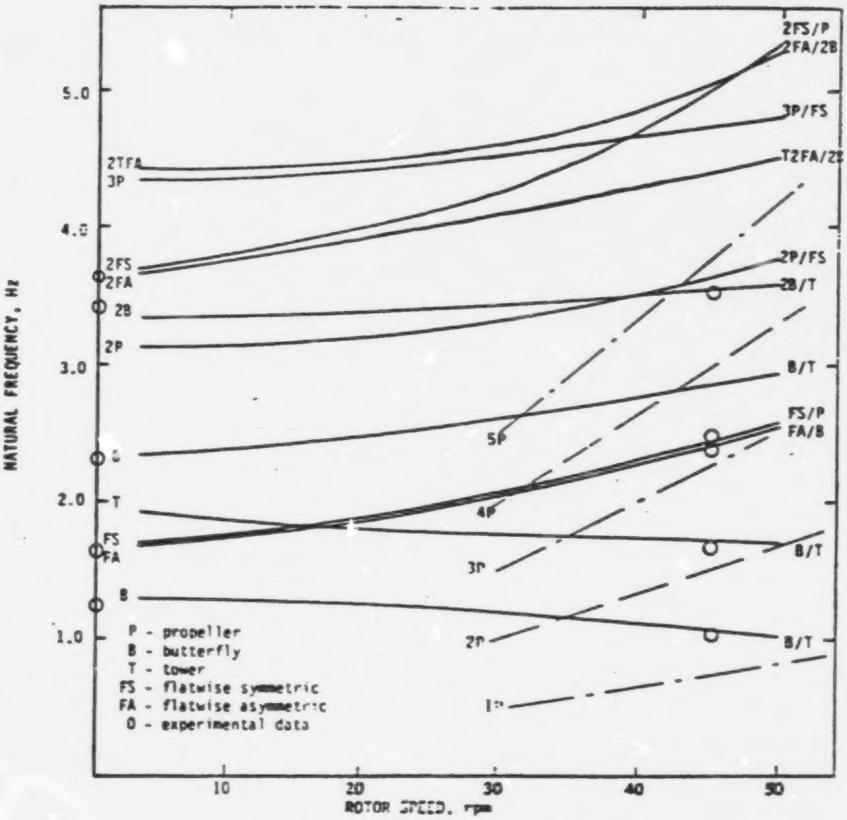
Damage due to fatigue accumulated more quickly in the intermediate configuration because the predominant stresses occurred at 3 P (2.25 Hz) instead of at 1 P (.75 Hz) as in the original design (see Figures 1 and 2).



ORIGINAL CONFIGURATION

INTERMEDIATE CONFIGURATION

Figure 1



NEW CONFIGURATION - FLEXI STRUTS
NATURAL FREQUENCIES VS ROTOR SPEED

Figure 2

Following the blade failure described in the NRC report referred to earlier, other causes of fatigue damage were reported by NRC. They were intergranular corrosion, sharp edges due to machining and possible fretting.

While none of these three factors was predominately responsible for the damage, the accumulative effect produced higher than anticipated stress concentration around the attachment holes.

Thus; the blade failure was due to higher stresses caused by a combination of strut lock up and stress risers caused by machining marks around the attachment holes, intergranular corrosion, and fretting.

The failure would not have occurred so soon had the operating stresses not exceeded those measured in the original design.

NEW ROTOR CONFIGURATION

Struts

The most obvious (visual) difference is the struts. The flexible struts are much simpler than the damper beams installed in the original configuration. This is an attractive fix since the stepped I-beam is easily made (Figure 3). Great care was taken when the flanges were flame cut to preserve the surface finish. This was to make sure minimum fatigue and maximum life from the I-beam.

The hinge, as we refer to it, is the pivot required where the blades meet the struts. The original design was complicated by the fact that the tubes for the A-frame had to terminate at a detail which would allow the body of the hinge to bolt up to it, but the new hinge block takes advantage of the fact that the I-beam provides an ideal mounting location. With no further modifications or welding, it can be bolted up directly through the web.

Another difficulty experienced in the original configuration was that the strut hinge had a tendency to seize up. So that checks could be made in the field, the new design allows the hinge to be unbolted easily to determine if it is free to move or not. In every case the dimensions of the pin and bushings have been increased, and the bushings are now made of a self lubricating material. This material has a much higher galling threshold than did the original.

All of this increases our margin of safety by lowering the component stresses.

Column

The original column was retained. This meant that the strut attachment provisions would require field modifications. The original rotor had a short beam running through the column perpendicular to the plane of the blades. The two ends of this beam provided the attachment for the A-frame struts. The new flexi struts go through the column in the plane of the blades 18" further from the centre of the rotor than did the original struts and terminate in a similar fashion

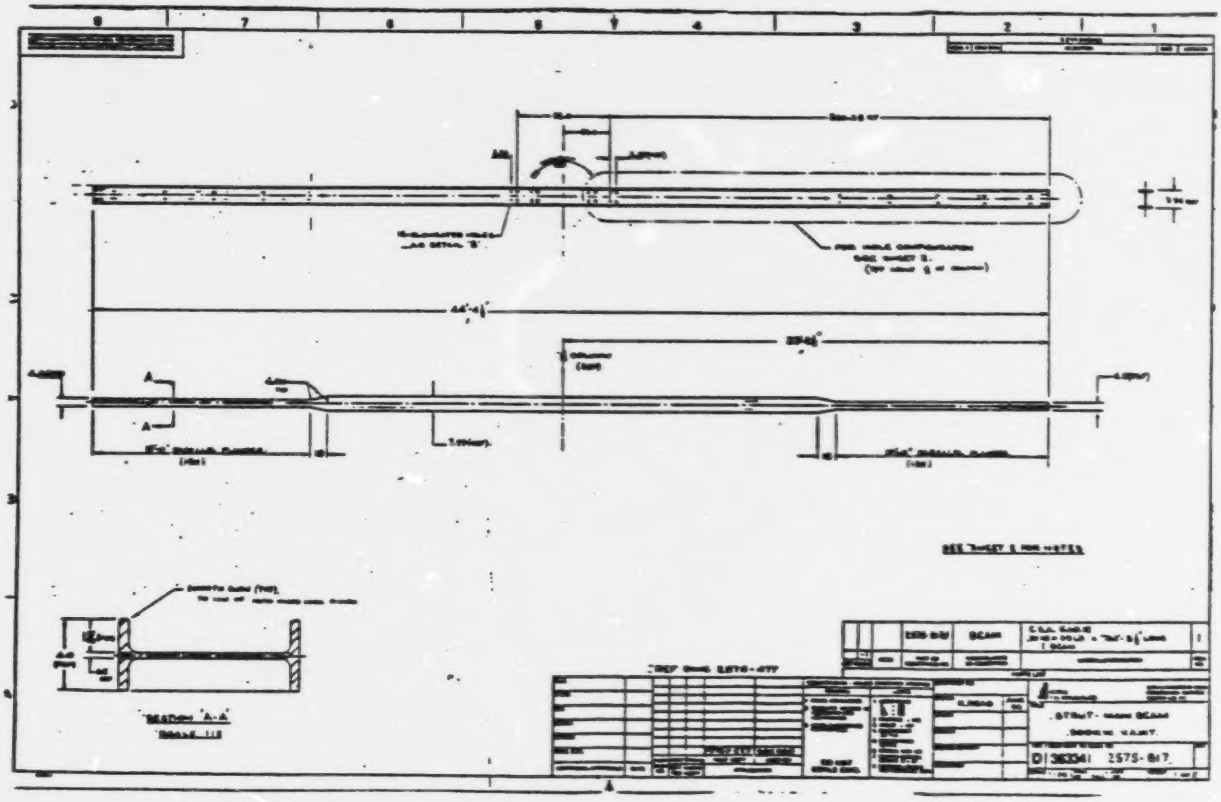

8
7
6
5
4
3
2
1
A
A
SECTION A-A
BEAM
STRUT
D 363341 2575-817

Figure 3

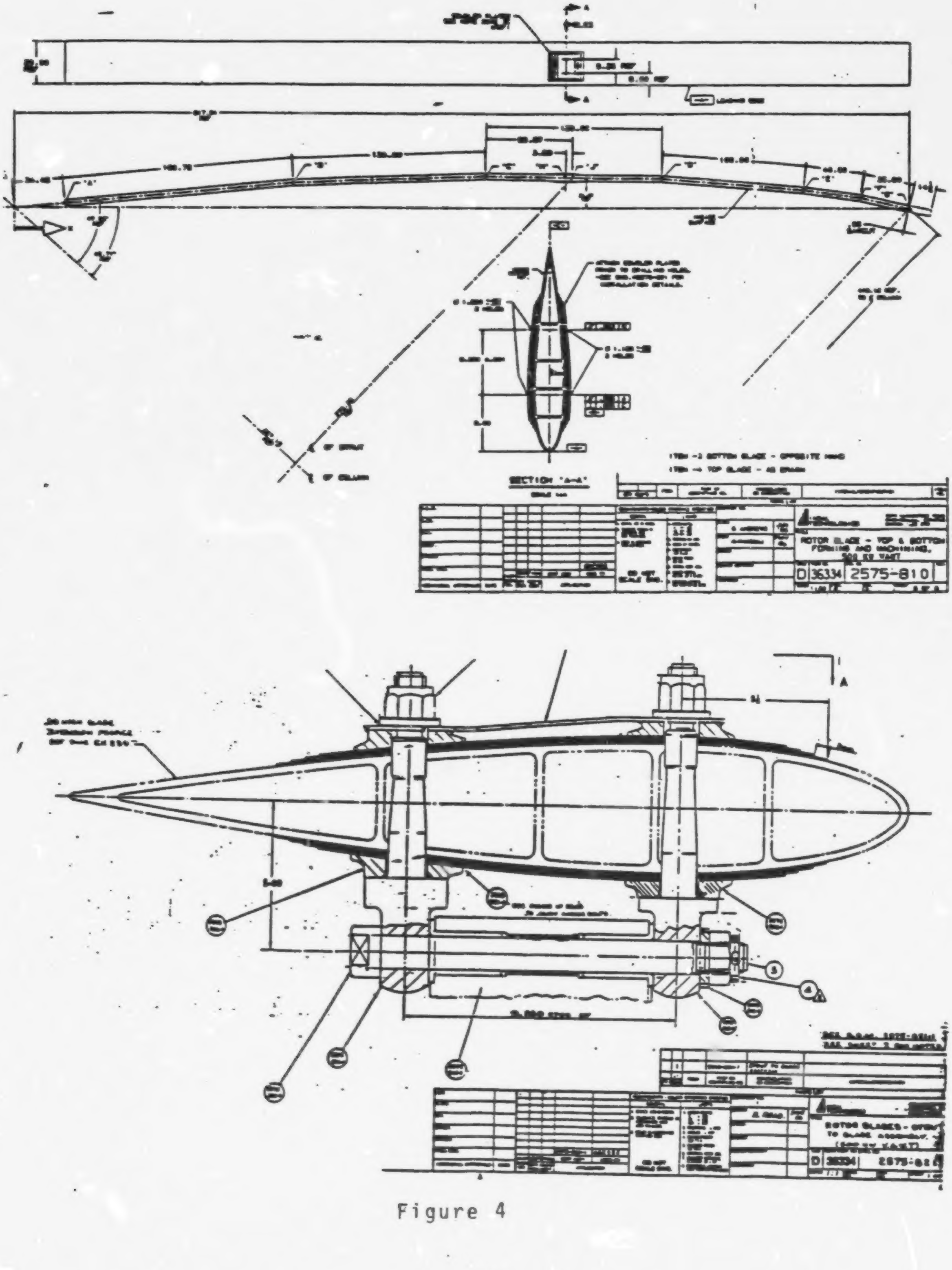

SECTION "A-A"
ITEM -2 BOTTOM BLADE - OPPOSITE HAND
ITEM -1 TOP BLADE - AS DRAWN
ROTOR BLADE - TOP & BOTTOM FORMING AND MACHINING, 500 KW VAWT
D 36334 2575-810
ROTOR BLADES -
D 36334 2575-82

Figure 4

at the blades. The column was reinforced with 1" and 3/4" A36 plates around the opening in the column. This modification was performed in the field since the column was not dimensionally exact enough to make these doublers in our shop and still expect them to fit without distorting the column (this was our goal).

The struts were attached to the doubling plates with angles on both the inside and outside and top and bottom. This gave us extra bearing area over angles on the outside only, even though it made the assembly activity much more difficult.

Blades

The blades remain unchanged with the exception of the particular attention paid to the strut to blade detail. ITI chose to strengthen this portion of the blades by bonding four doublers on each side with a structural epoxy (Figure 4). The blades were first treated by etching and rinsing, followed by a coat of primer to prevent the migration of corrosion under the epoxy. The doublers had been previously bent to the blade curvature and had been primed. Once we were certain that all doublers were fitting up properly the epoxy was applied and all was clamped and baked.

If any number of machines are to be turned out with blade doublers some improved methods will certainly be developed.

The final operation was the drilling/reaming operation for the hinge bolts. The holes had to be located very precisely with respect to each other and to minimize the chance of having any stress risers the hole was reamed to final dimensions with a specially designed reamer. The holes through the blades were stepped so that we would not run the risk of broaching the hole in the inside face of blade as we seated the 8" hinge bolts.

Another improvement was the hinge bolt and the hinge pins. In the original design these had been made from 17.4 PH heat treated to provide the maximum tensile strength. After looking carefully at the original design it was decided that we could improve the design by changing from H900 condition for these parts, to H1025 instead. In simple terms although we got benefits in tensile strength at H900 condition we did not achieve significant gains in fatigue strength. As well as not gaining anything in terms of fatigue, we lost a lot in terms of susceptibility to stress corrosion cracking. This is a small point but one worth mentioning since it seems to be a common occurrence in machine design problems.

The component we ended up with was more desirable since it delivered better fatigue life although its yield strength was lower.

Conclusions

We have been testing the new design since April 1987 and so far the experimental results agree with the predicted results from the ITI structural model. We have more testing to do to confirm that at all wind speeds the stress levels meet our design goals.

ITI will continue to monitor this machine and learn even more about making reliable, fatigue resistant vertical axis wind turbines.

References

"Investigation of VAWT (AQUILO) "A" Blade Failure at the Atlantic Wind Test Site, PEI".
Ref. LTR-ST-1582 NRC/NAE
R.V. Dainty, D. Chow

"Initial Analysis of Structural Data"
DAF 6400 Rotor Revised Configuration Prepared for Southern California Edison
R. E. Akins

STOCHASTIC WIND EFFECTS ON VERTICAL AXIS WIND TURBINES

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and I. Paraschivoiu

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Ecole Polytechnique de Montréal

Paper presented at:

Canadian Wind Energy Conference '87

Calgary, Alberta

September 27 – 30, 1987

STOCHASTIC WIND EFFECTS
ON VERTICAL AXIS WIND TURBINES

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Canada, H3C 3A7

ABSTRACT

Over the past decade, significant progress has been made in the development of the aerodynamic models for studying the Darrieus rotor VAWT. These models are based on momentum methods, vortex methods and finite difference methods.

Until now, all the aerodynamic loads and performance have been calculated based on a constant ambient wind and no significant attempts were made to examine the effects of atmospheric turbulence on the rotor. In this work we introduce a stochastic wind model into the double-multiple streamtube model in order to predict more accurately VAWT response characteristics.

The CARDAAV computer code based on the double-multiple streamtube model was used for determining the interference factors in the induced velocity on the upwind and downwind zones of the rotor and hence for estimating the aerodynamic forces. This computer code included the so-called "secondary effects" as well as the blade geometry and profile type, the rotating tower and the presence of struts and aerodynamic spoilers and vertical variation in the freestream velocity can be accounted for.

The CARDAAV code is first required to calculate the deterministic periodic flow velocities, independent of wind turbulence, then they are mixed with those of the stochastic simulation to yield total velocities. The fluctuation velocities, due to the atmospheric turbulence, are represented by a Fourier time-series. The Fourier coefficients are given in terms of spectral power density, the frequency band and a random phase angle for a specified rotor blade section.

The work presented in this paper is to compare the double-multiple streamtube predictions including stochastic wind effects with experimental data for Sandia 17-m machine. Thus we will compare forces using a turbulent wind with those calculated by using a constant ambient wind and also with the field experimental data at tip speed ratio of X_{eo} = 2.33, 4.60 and a rotational speed of 38.7 rpm.

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* Researcher Assistant
** Ph. D. Student
*** Professor

NOMENCLATURE

c = blade chord, m
C_D = blade airfoil section drag coefficient
C_L = blade airfoil section lift coefficient
C_N = blade airfoil section normal-force coefficient
C_T = blade airfoil section tangential-force coefficient
F = non-dimensional spectral power density
h = height above ground, m
h_o = roughness height
H = half height of the rotor, m
ℓ = blade length, m
n = frequency, Hz
N = number of blades
N_P = number of points in the time-series
R = rotor radius at the equator, m
R_{eb} = blade Reynolds number
s = rotor solidity, $= Nc\ell/S$
S = rotor swept area, m²
$U(x)$ = local velocity, m/s
U_w = wake velocity, m/s
$\overline{U}$ = mean wind velocity, m/s
V = upwind induced velocity, m/s
V_D = downwind induced velocity, m/s
V_e = induced equilibrium velocity, m/s
V_∞ = wind velocity at the equator level, m/s
W = upwind relative inflow velocity, m/s
x = streamwise velocity location
x_{eo} = streamwise position at which the turbulence is generated
X_{EQ} = tip speed ratio at the equator
Z = local turbine height, m
α = upwind local angle of attack, deg.
α_w = atmospheric wind shear exponent
β = rotor maximum diameter/height ratio
δ = angle between the blade normal and the equatorial plane
ζ = non-dimensional cartesian coordinate $= z/H$
η^+ = normalized frequency
$\Delta\eta^+$ = dimensionless frequency band
σ^+ = dimensionless turbulence intensity
τ^+ = dimensionless time
θ = azimuthal angle, deg.
ω = turbine rotational speed, s⁻¹

subscripts

EQ = equatorial values
∞ = freestream conditions
∞_i = local conditions in the vertical directions

1. INTRODUCTION

A large amount of work has been done in recent years with regard to the aerodynamic behavior of vertical axis wind turbines (VAWT's). The most common design for such machines was first patented in 1931, by DARRIEUS [1]. This machine consists of one or more blades with airfoil cross section attached to the top and bottom of a central shaft or tower. During one revolution alone, significant periodic variation occurs in the flow direction, relative velocity, and angle of attack. Furthermore, the airflow is cut twice by blades during one cycle with the result that the downwind half-cycle of the rotor is strongly disturbed by the upwind half-cycle.

In order to analyze the aerodynamic characteristics of the VAWT many numerical approaches has been proposed. They are broadly divided into three categories according to whether they are based on the momentum method, vortex method, or finite difference method. In each method the problem is to evaluate the flow velocities through the rotor and calculate the blade forces by using static lift and drag coefficients data obtained from wind tunnel measurements.

In the first approach, classified as single streamtube model [2], multiple streamtube model [3], and double-multiple streamtube model [4], it is assumed that the flow through the rotor can be modeled by examining the flow through one or more streamtubes. In the most complicated case, double-multiple streamtube, the induced velocities vary in the upwind and downwind regions of the streamtube as well as varying from one streamtube to the other. The second approach for analyzing the aerodynamic characteristics of the VAWT is based upon some form of the vorticity equation and employs two types of vortex model to predict the flow field around VAWT, these are referred to as "fixed-wake" [5] and "free-wake" [6]. On the other hand, the third category method is based on a finite difference procedure in inviscid flow [7] and more recently in viscous flow [8].

To date, all the aerodynamic analysis of the load and performance of the VAWT's based on the methods described above are concentrated on a constant incident wind. As a result, the calculated forces on the blade are identical for each rotation and, in this case we do not have any informations concerning the turbulent wind effects on the wind turbine. The investigation herein is to provide one tool to estimate these effects on the wind turbine by introducing a stochastic wind model into the double-multiple streamtube model.

The first part of this paper describes the rotor model based on the double-multiple streamtube including the basic equations and the aerodynamic computer code. The second part is related to the stochastic wind simulation and analytical results are compared to those obtained from a constant ambient wind and also to experimental data on Sandia Laboratories site for the 17-m wind turbine.

2. AERODYNAMIC MODEL

2.1 Double-multiple streamtube model (DMS)

The aerodynamic analysis on the 17-meters VAWT rotor blades were calculated using the analytical approach based on the momentum principle and blade element theory (Double-Multiple Streamtube). This analytical method uses a multiple-streamtube model and is divided into two parts: one for modeling the upstream half-cycle of the rotor and the other for the downstream half-cycle.

The upwind and downwind components of the induced velocities at each level of the rotor are calculated by using the principle of the two actuator disks in tandem, as shown in Fig. 1. The freestream velocity profile is given by the following equation:

$$V_{\infty i}/V_{\infty} = (Z_i/Z_{EQ})^{\alpha w} \qquad (1)$$

The upwind velocity component is less than the local ambient wind velocity and in the middle plane between the upwind and downwind zones there is an equilibrium-induced velocity. Thus the induced velocity decreases in the axial streamtube direction so that the downwind component is less then the equilibrium velocity and the latter smaller than the upwind component.

The streamwise blade force as well as the normal and tangential force are evaluated for each streamtube as a function of the blade position. The upwind non-dimensional normal and tangential force as function of the azimuthal angle are given by [4]:

$$F_N(\theta) = (cH/S) \int_{-1}^{1} C_N (W/V_\infty)^2 \, (1/\cos\delta) \, d\zeta \qquad (2)$$

$$F_T(\theta) = (cH/S) \int_{-1}^{1} C_T (W/V_\infty)^2 \, (1/\cos\delta) \, d\zeta \qquad (3)$$

Where:

$$C_N = C_L\cos\alpha + C_D\sin\alpha \qquad (4)$$

$$C_T = C_L\sin\alpha - C_D\cos\alpha \qquad (5)$$

The blade airfoil section lift and drag coefficients, C_L and C_D, respectively, are obtained by interpolating the available test data using both the

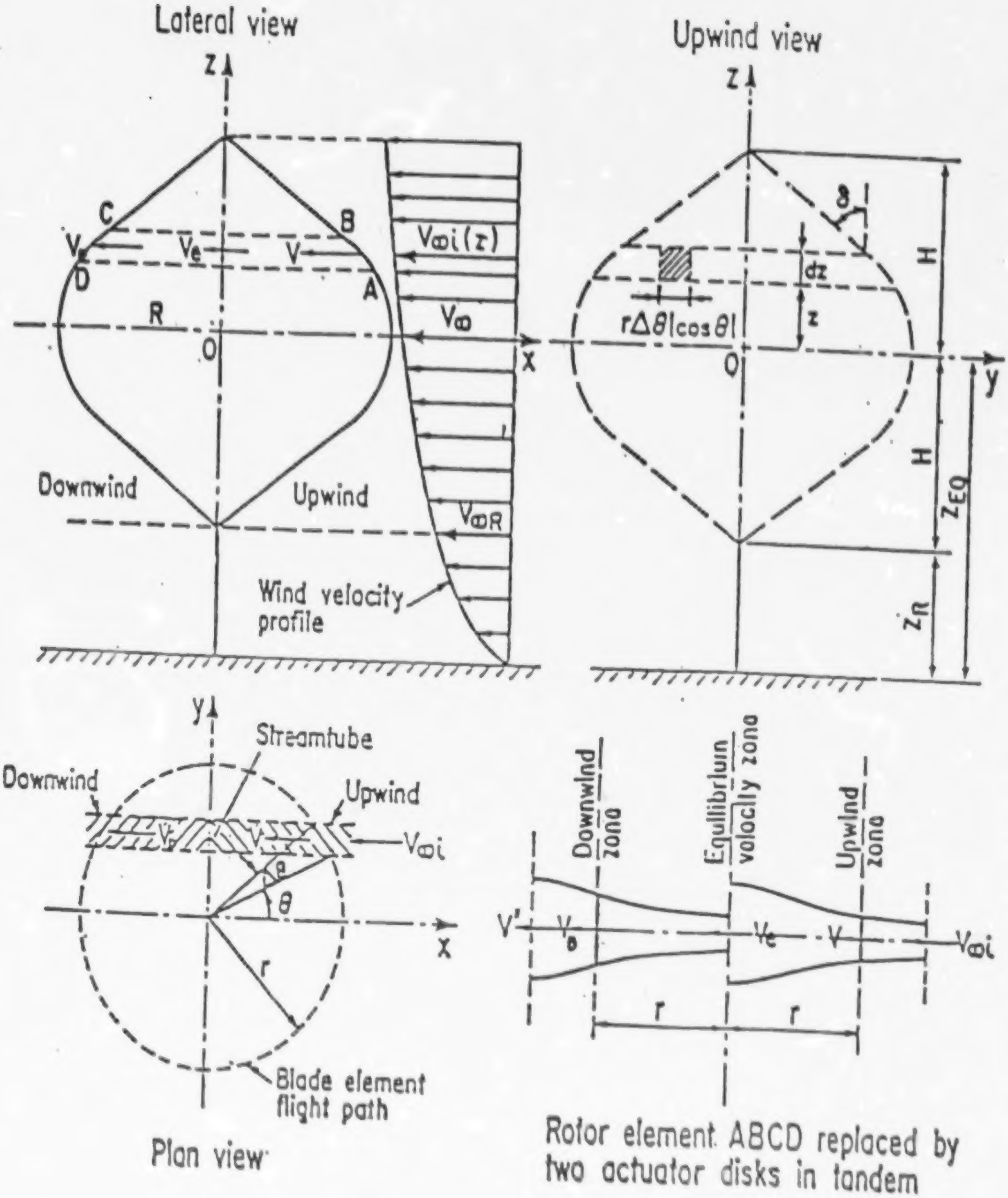
Lateral view
z
C
B
V'
Ve
V
Vωi(z)
D
A
R
O
V∞
x
Downwind
Upwind
V∞R
Wind velocity profile
Upwind view
z
δ
dz
rΔθ|cos θ|
z
H
O
y
H
ZEQ
Zn
y
Streamtube
Downwind
Upwind
V'
Ve
V
V∞i
θ
x
r
Blade element flight path
Plan view
Downwind zone
Equilibrium velocity zone
Upwind zone
V'
Vo
Ve
V
V∞i
r
r
Rotor element ABCD replaced by two actuator disks in tandem

Fig. 1 Rotor geometry for Darrieus wind turbine. Two actuator disks in tandem.

local Reynolds number and the local angle of attack.

Equations (2) and (3) allow the normal and tangential load distribution on the turbine blade to be calculated at typical values of the azimuthal angle θ.

Similarly, for the downwind half-cycle of the rotor we can calculate the normal and tangential force coefficients by using equations (2) and (3) where velocities and blade force coefficients are those corresponding to the downstream flow conditions. The method is comprehensively described in references [4] and [9].

2.2 Aerodynamic computer code

The aerodynamic blade loads of the rotor were calculated by using CARDAAV computer code. This code has a first variant named CARDAA [9] which uses two constant interference factors in the induced velocities, one for each half-streamtube. Then it has been improved by considering the variation of the interference factors as a function of the azimuthal angle on the upwind and downwind half of the rotor [4]. In this case, it is referred to as CARDAAV.

The computer program comprises a main program and several subroutines as well as a Simpson function for numerical integration. A subroutine AERO is used for evaluating rotor local aerodynamic characteristics with CLCD subroutine for computing the blade section characteristics by interpolation as a function of the Reynolds number R_{eb} and the angle of attack α. GEOM subroutine allows several blade shapes of the rotor to be computed [10].

The input data consists on the geometrical parameters of the rotor, that is the number of blades N, the airfoil blade section (generally a NACA symmetrical profile), the solidity $s = Nc\ell/S$, and the radius to half-height, $\beta = R/H$. The freestream velocity is selected from equation (1) and the equatorial tip speed ratio ($X_{eo} = \omega R/V_\infty$) is chosen, thus forming a set of input data .

The output data that can be obtained are: the local induced velocities, the local Reynolds number R_{eb} and the calculated angle of attack, the blade loads, and the instantaneous torque and power coefficient. Each of these is calculated separately for the upwind and downwind of the rotor and finally all the rotor characteristics are given as an output data.

For all results presented in this paper, the calculation were made at every azimuthal angle θ of 5°. Determination of the aerodynamic blade loads for the Darrieus wind turbine, based on the double-mutiple streamtube model with CARDAAV computer code produces a reasonable results and requires much less computer time with respect to the vortex theory model and to the finite difference method.

3. WIND MODEL

The objective of the wind model is to yield turbulent wind velocity fluctuations for rotationally sampled points. The one dimensional variations of this turbulent wind are produced by creating a wind time series at a fixed point upwind the rotor and assuming that the wind speed is constant in a plane perpendicular to the mean wind direction. By applying Taylor´s frozen turbulence hypothesis, the turbulent wind speed at downstream of the fixed point can be obtained by calculating a time delay in the time series. The general method of this model was given by Veers [11] and developed later, by Strickland [12]. The decrease in the streamwise velocity as the flow passes through the wind turbine rotor is taken into account by assuming a linear variation in the streamwise direction as given by Fig. 2.

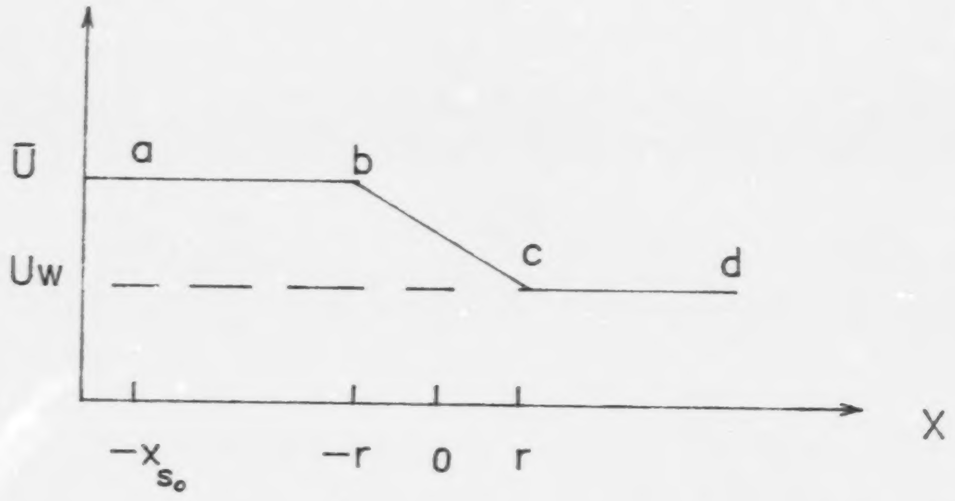

Fig. 2 Streamwise velocity distribution.

The spectral power density used in the present work is that given by Frost, Long and Turner [13]:

$$\xi_w = \left[\frac{\sigma^2}{n}\right] \frac{0.164\ (\eta^*/\eta_o)}{1 + 0.164\ (\eta^*/\eta_o)^{5/3}} \qquad (6)$$

Where $\eta^* = nh/\bar{U}$ and η_o is a constant which depends upon the streamwise direction x, the lateral direction y, and the vertical direction z (η_o = 0.0144, 0.0265 or 0.0962).

The turbulence intensity σ is given by:

$$\sigma = \frac{\overline{U}\, C}{\ln(h/h_o + 1)} \tag{7}$$

With the constant C equal to 1.00, 0.64 or 0.52 depending on the fluctuation directions used.

The non-dimensionalized spectral power density normalized with the height above the ground, the mean velocity, and the turbulence intensity is set according to Strickland [12] as:

$$F = \frac{\Phi_w\, \overline{U}}{h\ \sigma^2} = \frac{0.171/\eta_o}{1 + 0.164(\eta^+/\eta_o)^{5/3}} \tag{8}$$

The fluctuation velocities due to the turbulent wind are represented by a Fourier time-series. This series are written as:

$$V^+ = \sigma^+ \sum_{j=1}^{N_p/2} \left[A_j^+ \sin(2\pi\eta_j^+\tau^+) + B_j^+ \cos(2\pi\eta_j^+\tau^+) \right] \tag{9}$$

Where the turbulence intensity σ and the fluctuation velocity V' are normalized by $\overline{U}$ as:

$$\sigma^+ = \frac{\sigma}{\overline{U}} \qquad V^+ = \frac{V'}{\overline{U}} \tag{10}$$

The Fourier coefficients are given in terms of the non-dimensional spectral power density, the dimensionless frequency band $\Delta\eta^+$ and a random phase angle Φ_j by the following equations:

$$A_j^+ = (2\ F_j\ \Delta\eta^+)^{1/2} \sin\Phi_j \tag{11}$$

$$B_j^+ = (2\ F_j\ \Delta\eta^+)^{1/2} \cos\Phi_j \tag{12}$$

Where The time τ is non-dimensionalized by the mean velocity and the height above ground ($\tau^+ = \tau\,\bar{U} / h$).

The summation process of equation (9) is to be carried out for $j = 1$ to $N_P/2$ and is performed by using the Fast Fourier Transform. A typical time-serie simulation of the wind velocity fluctuations is given by Fig. 3, where the turbulence intensity in the longitudinal and lateral directions is equal to 20% and 18% respectively.

For the moving nodes the time delay $\Delta\tau_D^+$, at any position x, is obtained from the integral:

$$\Delta\tau_D^+ = \frac{\bar{U}}{h}\int_{x_{wo}}^{x}\frac{dx}{U(x)} \tag{13}$$

Using the form of the velocity distribution U(x) given by Fig. 2 the time delay will have the following form:

$$\Delta\tau_D^+ = \frac{r}{h}\left[\frac{1}{c_2}\ln\left(c_1 + c_2\frac{x}{r}\right) - \frac{x_{wo}}{r} - 1\right] \tag{14}$$

Where the coefficients c_1 and c_2 are a function of the wake velocity U_w and are given by:

$$c_1 = \frac{1}{2}\left(\frac{U_w}{\bar{U}} + 1\right) \tag{15}$$

$$c_2 = \frac{1}{2}\left(\frac{U_w}{\bar{U}} - 1\right) \tag{16}$$

Finally, the position of all specified nodes can be determined. That is the nodes 1 and 2 which are moving with the rotor and the node 3 which is fixed at the streamwise location where the turbulence is generated.

The integration of the wind model into the aerodynamic model (DMS) has been done in the manner described below.

We have the aerodynamic model of the rotor, wherein, the forces are calculated without introducing the atmospheric turbulence and we use the stochastic wind simulation to yield turbulent wind-velocity fluctuations. The CARDAAV computer code is broken up into two parts. The first part is required to calculate the flow velocities with a constant steady wind, then they are mixed with those given by the stochastic simulation to yield total flow velocities. Finally, rotor force distributions in the presence of the turbulent wind are computed by using these total flow velocities.

4. RESULTS AND DISCUSSIONS

In order to analyze the aerodynamic response of the vertical axis wind turbine in the presence of a turbulent wind, a stochastic wind model has been incorporated into the double-multiple streamtube model. A similar work has been done to study the effects of a turbulent wind on the structural response of Darrieus rotor [14] and also the effects on the rotor torque for Sandia 34-m [15]. In the present work we are interested on the effects of a turbulent wind on the rotor normal and tangential forces for Sandia 17-m so as to be able to compare the theoretical results with available experimental data [16], [17].

Instantaneous normal and tangential forces, were calculated by assuming both steady and turbulent wind in order to show the effect of the turbulence on the rotor. The results are given by Figs. 4 and 5. As it was expected, when a constant ambient (or a steady) wind is assumed the forces repeat exactly for each revolution of the rotor. However, with a turbulent wind, the response of the rotor is different and, at each revolution the instantaneous forces change their values.

To be able to choose the number of the simulations and revolution of the rotor, it was helpful for us to try many simulations until we reach a stationary result. This is given by Figs. 6 and 7 for normal and tangential force coefficients respectively. Results for 10, 20, 30, and 40 simulations indicate that with a 20 simulations we can reach the stationary results. This was an optimum for convergence and time consuming. On the other hand, the rotor revolution number was chosen from an experimental point of view [18] where the experimental data are taken for 5 minutes. In addition, because of the wind turbine rotational speed, which is 38.7 RPM, and to agree with the experimental data the number of revolution is 200 revolutions.

Figure 8 shows the distribution of the normal force coefficient as a function of the azimuthal angle for a tip speed ratio of $X_{eo} = 4.60$. The theoretical results with different turbulence intensity were compared with CARDAAV results by using a constant ambient wind and with experimental data [16]. Results plotted in this figure are the average of 20 simulations, they show a good agreement in the upwind and downwind regions with respect to the experimental data. Results indicate also that the experimental data are well predicted when the turbulence intensity increases.

At low tip speed ratio ($X_{eo} = 2.33$) and a different turbulence intensity levels the results plotted in Fig. 9 indicate that the distribution of the normal force coefficient is almost the same even with high turbulence intensity and show a good agreement with experimental data then the double-multiple streamtube results.

Figure 10 is plotted to compare the normal force coefficients for Sandia 17-m wind turbine at tip speed ratio of $X_{eo} = 4.60$ and a turbulence intensity of 27 % and 25 % in the longitudinal and lateral directions respectively, with experimental data. The average values has been taken for 20 simulations and 200 turbine revolutions. From preliminary comparison of this result, it became apparent that the effect of a turbulent wind can not be ignored. Results show a good agreement with experimental data in both regions of the turbine, that is the upwind and downwind regions. This figure indicates that almost all the experimental data are inside the envelope which is given by the average values plus or minus one standard deviation. It shows also the maximum and the minimum values of the normal force coefficients which exist at a specific azimuthal angle. The curves C_{Nu} and $C_{N\ell}$, defined in order to have a probability of 80 % of the instantaneous normal force coefficients between these curves indicate that the dispersion between the average values and experimental data is reduced. These behavior can also be seen in Fig. 11 at low tip speed ratio (X_{EQ} = 2.33) except in some regions where the experimental data are not well predicted.

The tangential force coefficients for three intensity levels of turbulence and a tip speed ratio of $X_{EQ} = 4.60$ are plotted in Fig. 12 with those predicted by the double-multiple streamtube. At the upwind region the tangential force coefficients decrease from low turbulence intensity to high turbulence intensity and have low values comparing to DMS results. For the downwind region, however, tangential force coefficients decrease from high turbulence intensity to low turbulence intensity until they reach the values given by a constant ambient wind. This can also be observed in the case of the normal force coefficients at high tip speed ratio, see (Fig. 8).

The tangential force coefficients with a turbulence intensity of 27% and 25% in the longitudinal and lateral directions respectively and a tip speed ratio of $X_{EQ} = 4.60$ are plotted in Fig. 13 . The average tangential force coefficients changes at the same manner of the double-multiple streamtube model with a constant steady wind, however the instantaneous values can have a high excursion about their average. This can be observed by the plot of C_{Tu} and $C_{T\ell}$ curves, defined in order to have a probability of 80 % of the instantaneous tangential force coefficients between these curves.

At low tip speed ratio ($X_{EQ} = 2.33$), the average values of the tangential force coefficients have a high deviation with respect to the double-multiple streamtube model (Fig. 14). This deviation became considerable when the turbulence intensity increases. The instantaneous tangential force coefficient have a high excursion between their average as shown by Fig. 15.

5. CONCLUSIONS

A stochastic wind simulation for Darrieus wind turbine has been used to yield turbulent wind velocity fluctuations for rotationally sampled points and incorporated into the double-multiple streamtube aerodynamic model in order to predict more accurately the wind turbine response characteristics.

Deterministic flow velocities from the double-multiple streamtube were mixed with the stochastic flow velocities which were computed from the stochastic simulation and used, afterwards, to predict forces on the rotor blades.

The computer code employed uses the same aerodynamic routines to predict both the response to the constant steady wind, and the stochastic response with turbulence presence.

The average distributions of the rotor forces using a turbulent wind do not coincide with the mean distributions produced by the double-multiple streamtube model when the constant steady wind is assumed.

At low turbulence intensities, the deviation between the averaged values and periodic force distributions is small. Nevertheless, the instantaneous values exhibit a significant high excursions about their average.

At high turbulence intensities, the discrepancy between the averaged and periodic force distributions increases, as does the magnitude of the instantaneous excursion.

When a high tip speed ratio is used the general behavior of the averaged tangential force distributions with different turbulence intensity levels changes weakly. However, for a low tip speed ratio it changes considerably especially when the turbulence intensity increases.

For the normal force distributions the behavior of the averaged values is almost the same at high or low tip speed ratio.

Finally, the analyses described herein will be helpful by having a more experimental data and by introducing a raisonable dynamic stall in order to have a more accurate results. Indeed, the dynamic stall model used until now does not give a good results with respect to the force distributions.

ACKNOWLEDGEMENT

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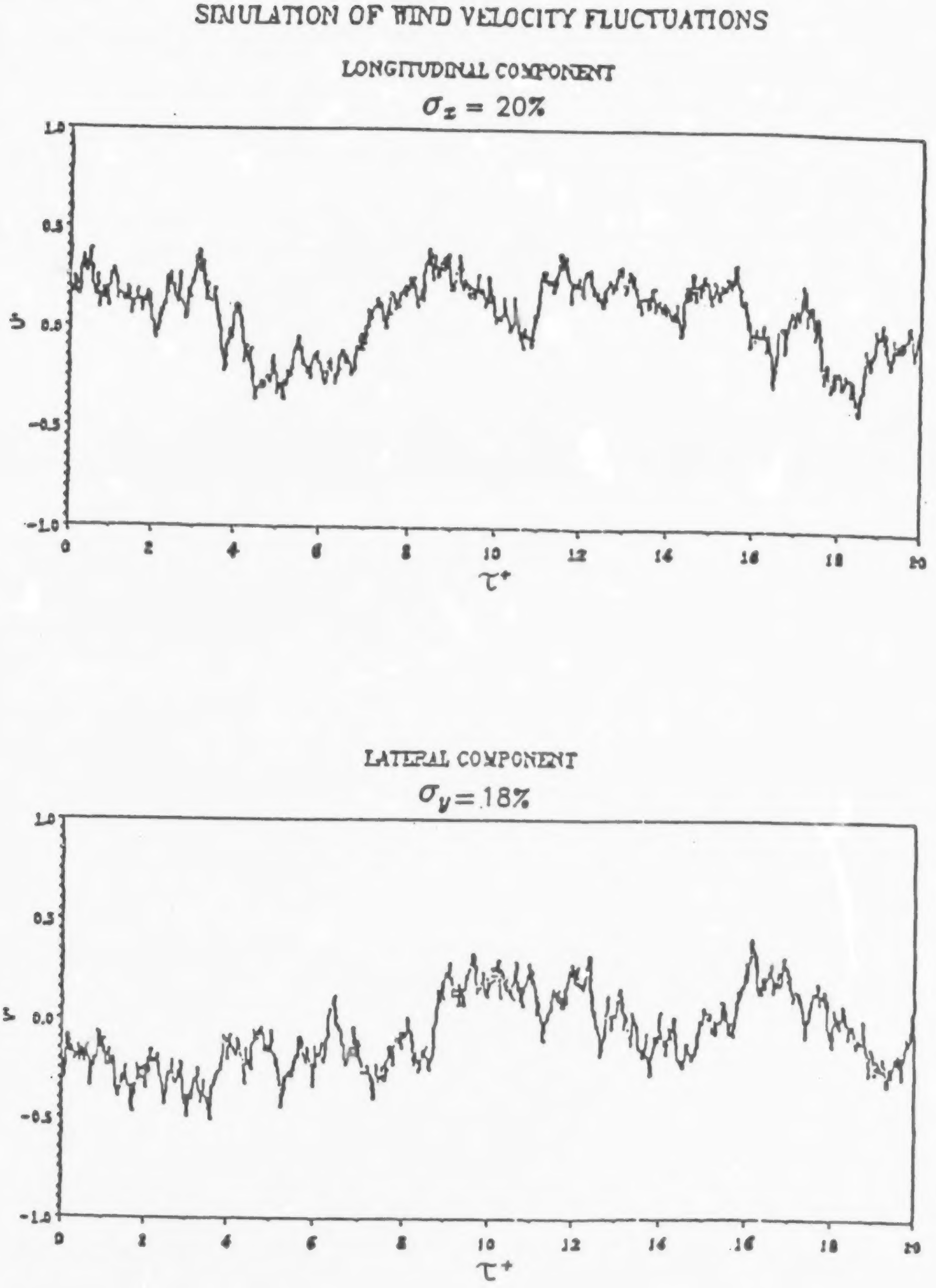


Fig. 3 Time–serie simulation of wind velocity fluctuations. Turbulence intensity = (20%, 18%)

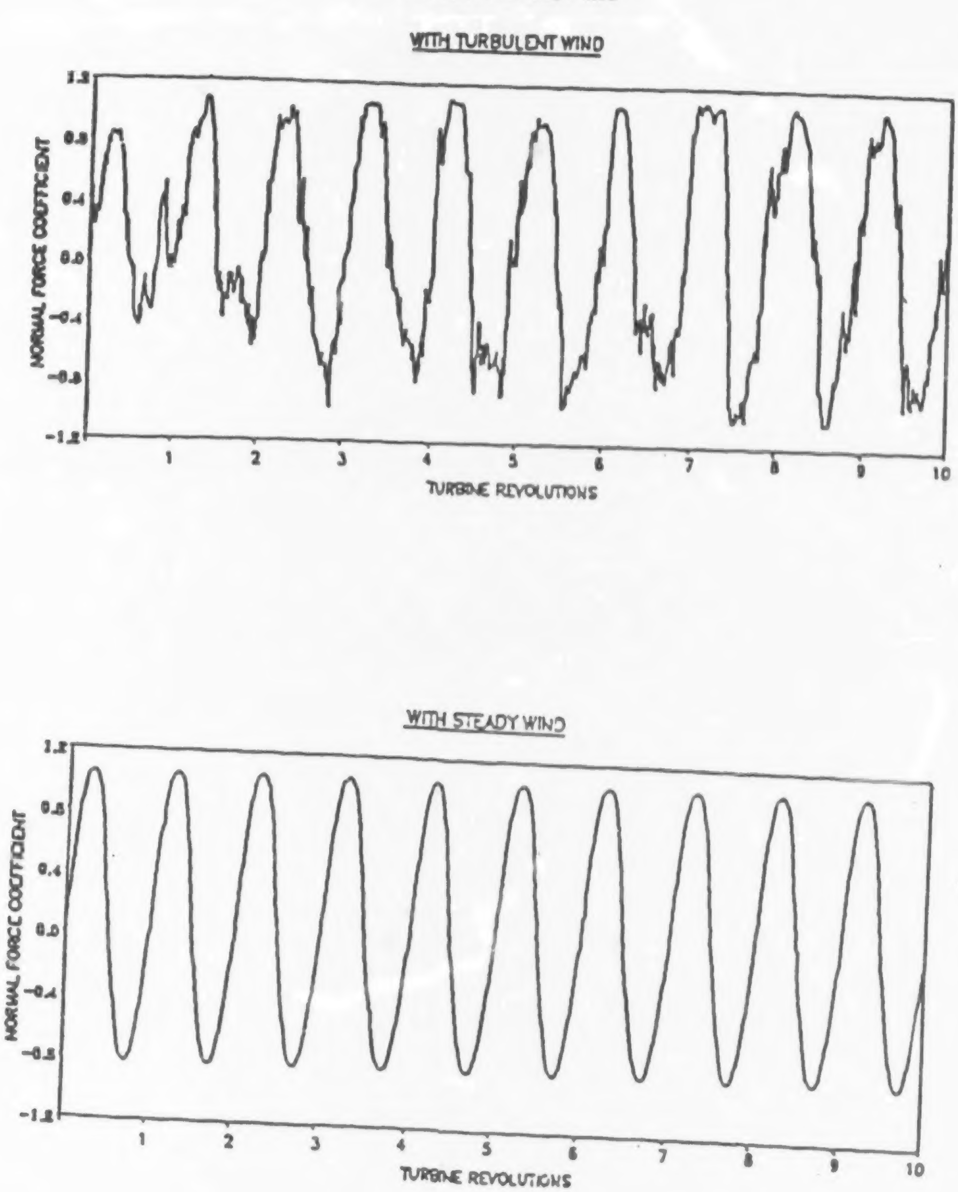


Fig. 4 Instantaneous normal force coefficient assuming a steady and turbulent wind.

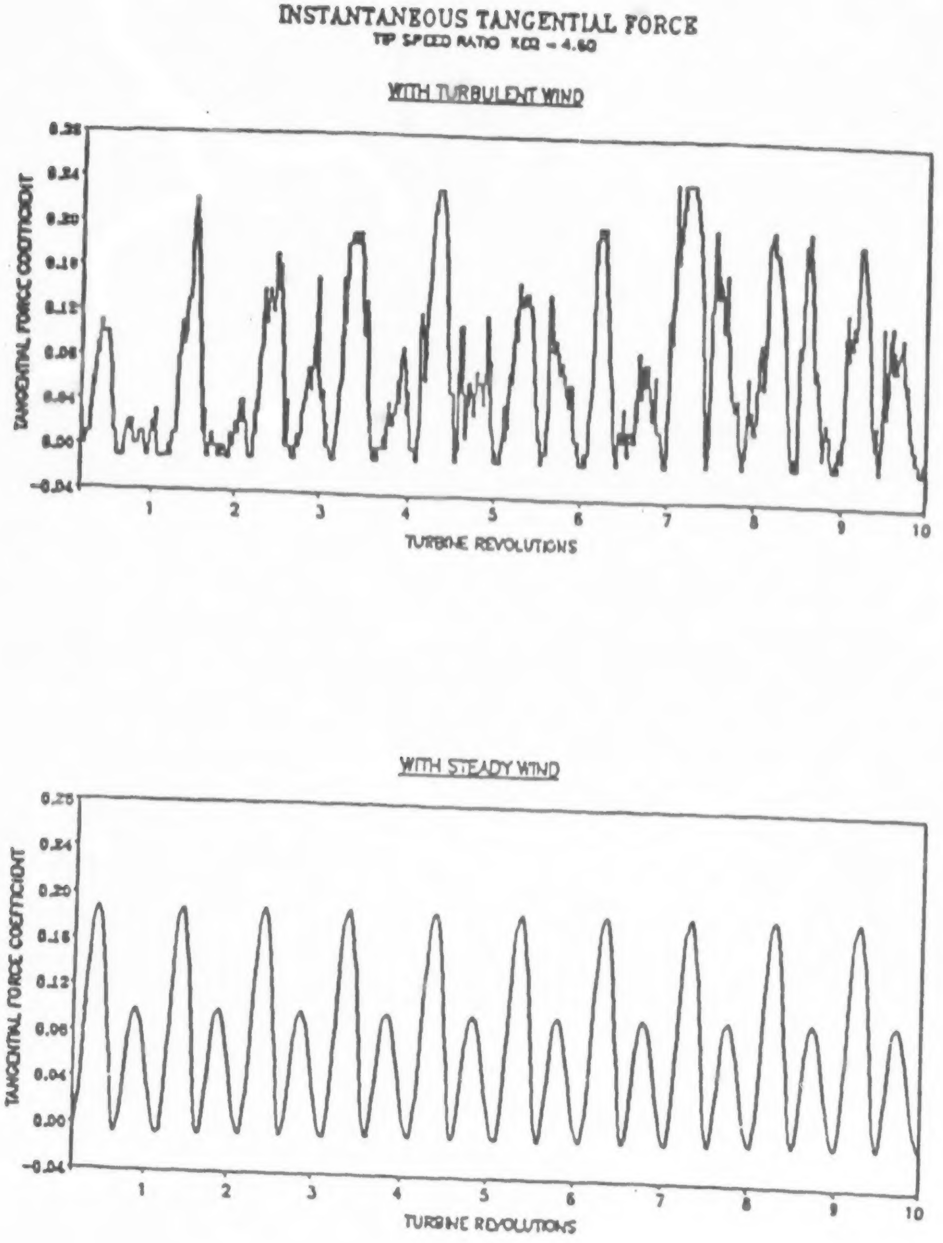


Fig. 5 Instantaneous tangential force coefficient assuming a steady and turbulent wind.

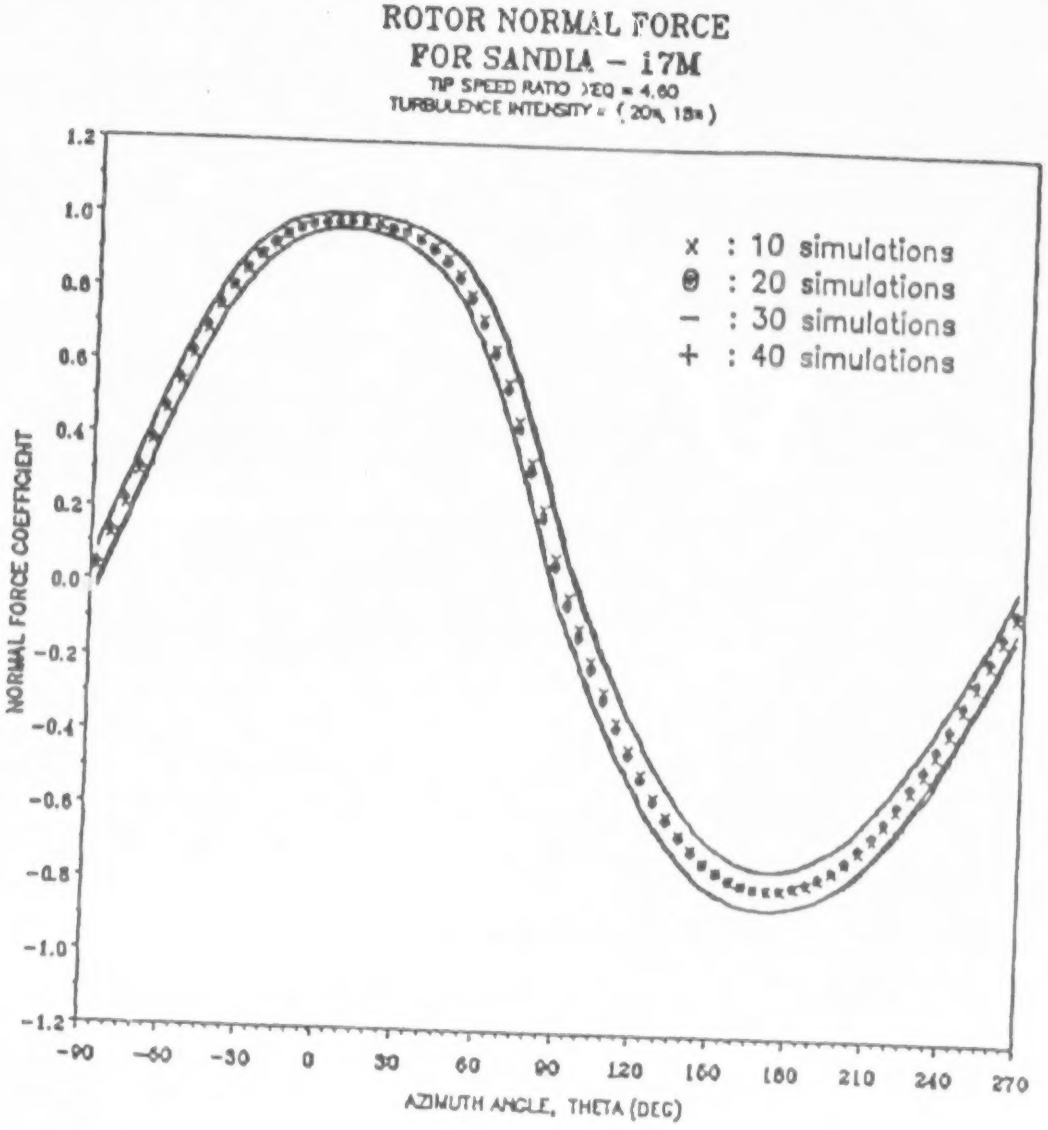


Fig. 6 Average rotor normal force coefficient for Sandia 17-m at XEQ = 4.60 with different simulation numbers.

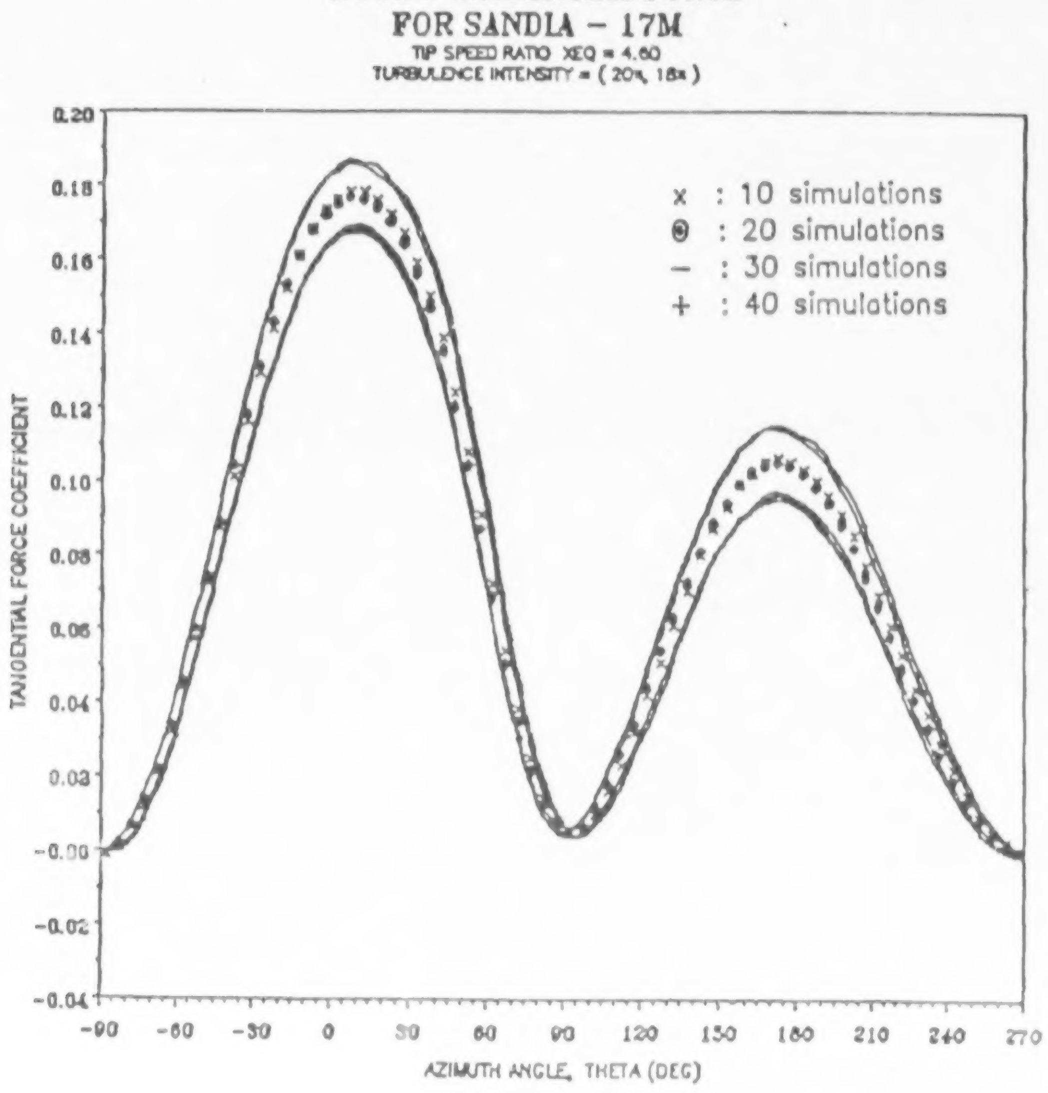


Fig. 7 Average rotor tangential force coefficient for Sandia 17–m at XEQ = 4.60 with different simulation numbers.

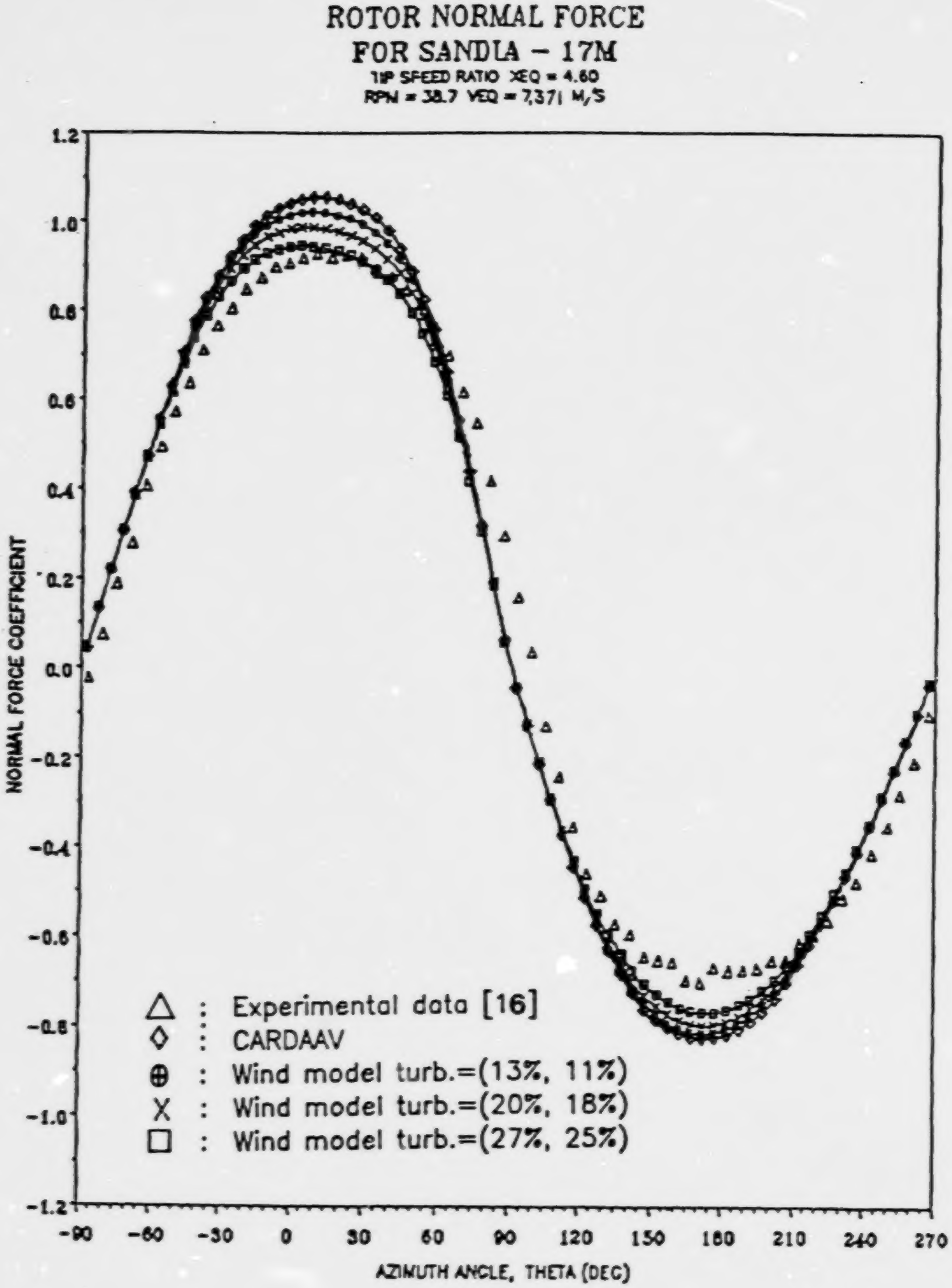


Fig. 8 Comparison of the normal force coefficient at three intensity levels with experimental data and CARDAAV results at XEQ = 4.60

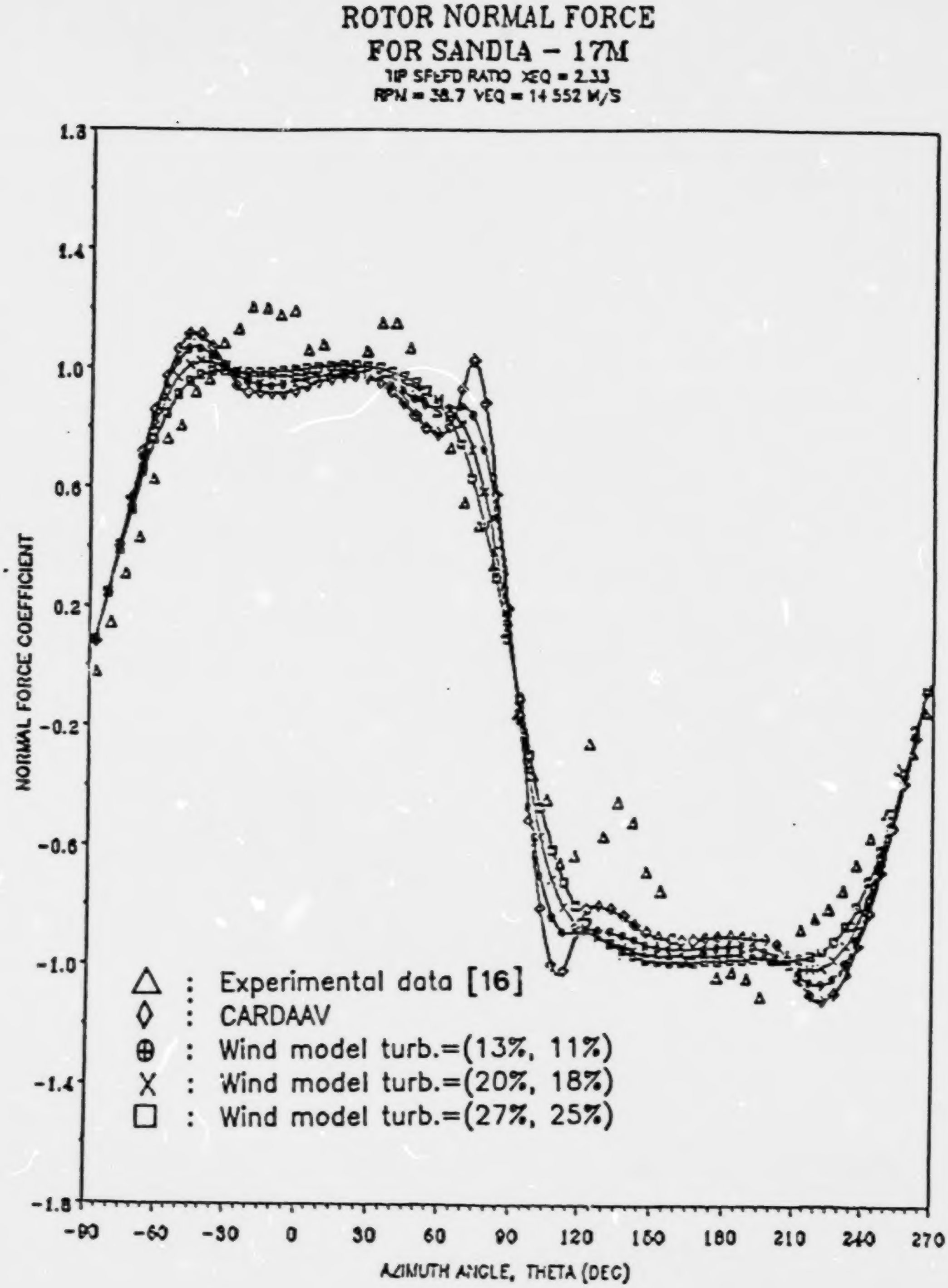
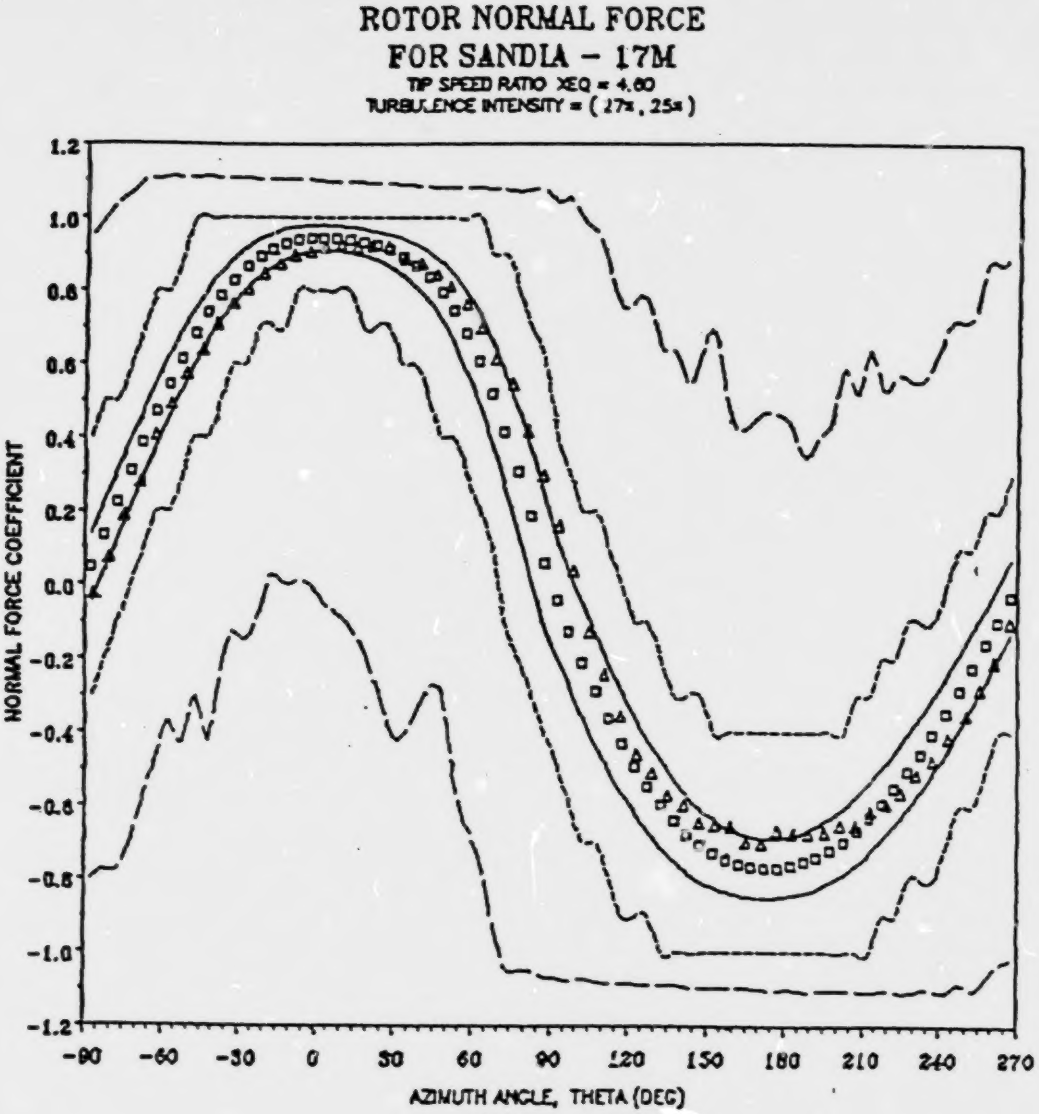


Fig. 9 Comparison of the normal force coefficient at three intensity levels with experimental data and CARDAAV results, at XEQ = 2.33



□ : Average values

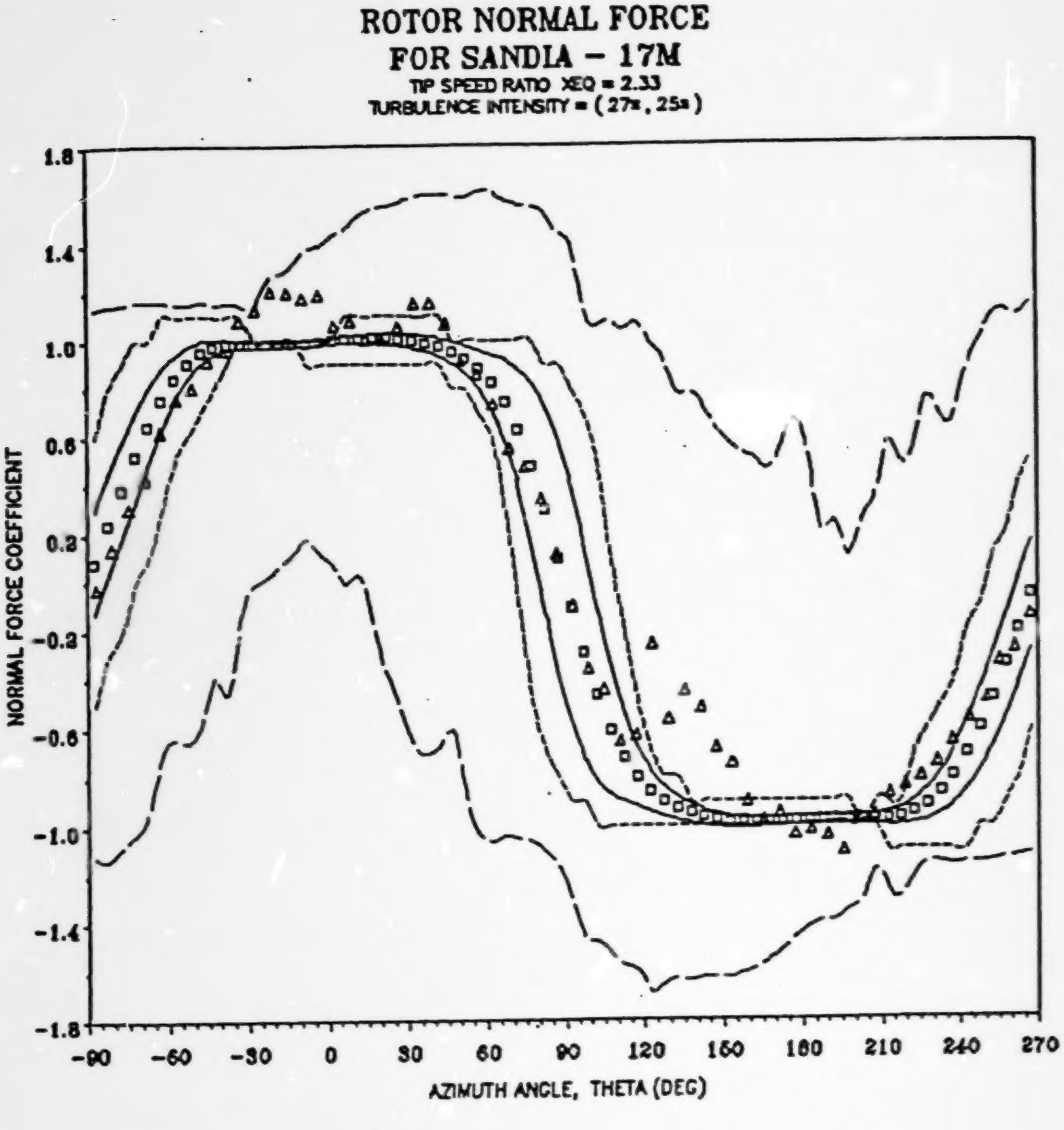
——— : Average values ± one standard deviation

— — : Minimum and maximum values

- - - - : CN_u (upper) and CN_ℓ (lower)

△ : Experimental data [16]

Fig. 10 Normal force coefficient with a longitudinal and lateral turbulence intensities = (27%, 25%) and XEQ = 4.60



□ : Average values
——— : Average values ± one standard deviation
— — : Minimum and maximum values
----- : CN_u (upper) and CN_ℓ (lower)
△ : Experimental data [16]

Fig. 11 Normal force coefficient with a longitudinal and lateral turbulence intensities = (27%, 25%) and XEQ = 2.33

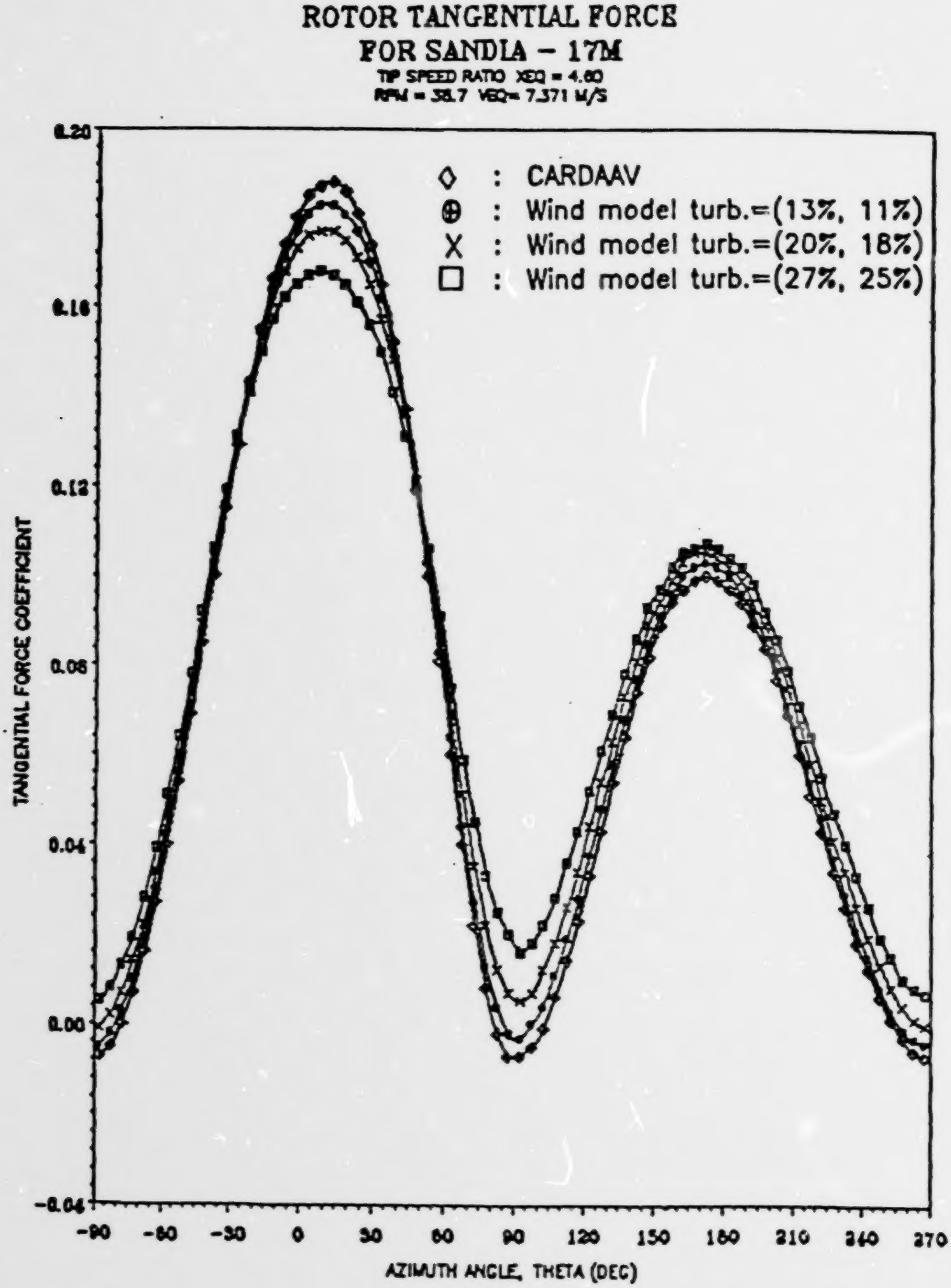


Fig. 12 Comparison of the tangential force coefficient at three intensity levels with CARDAAV results, at XEQ = 4.60

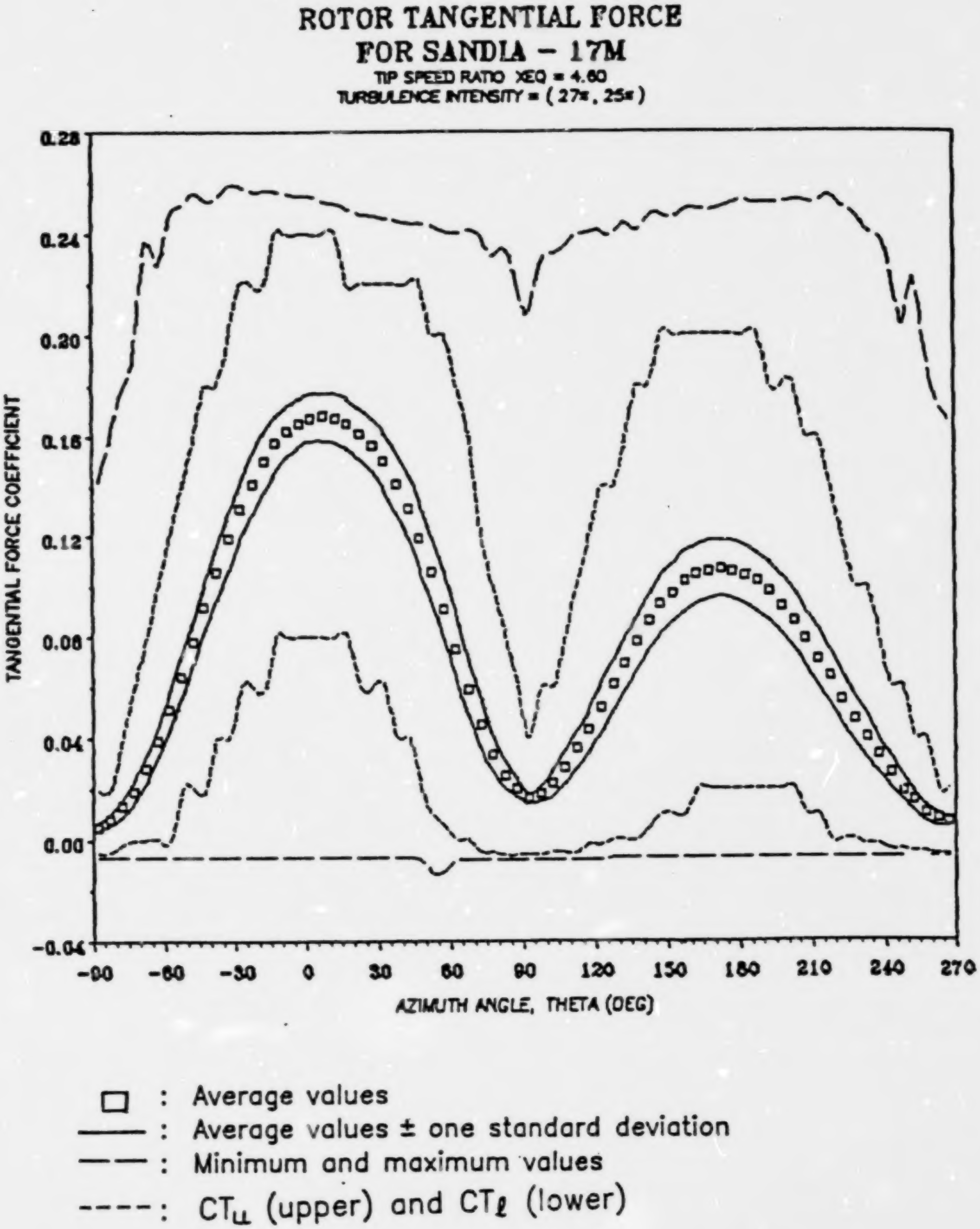


Fig. 13 Tangential force coefficient with a longitudinal and lateral turbulence intensities = (27%, 25%) and XEQ = 4.60

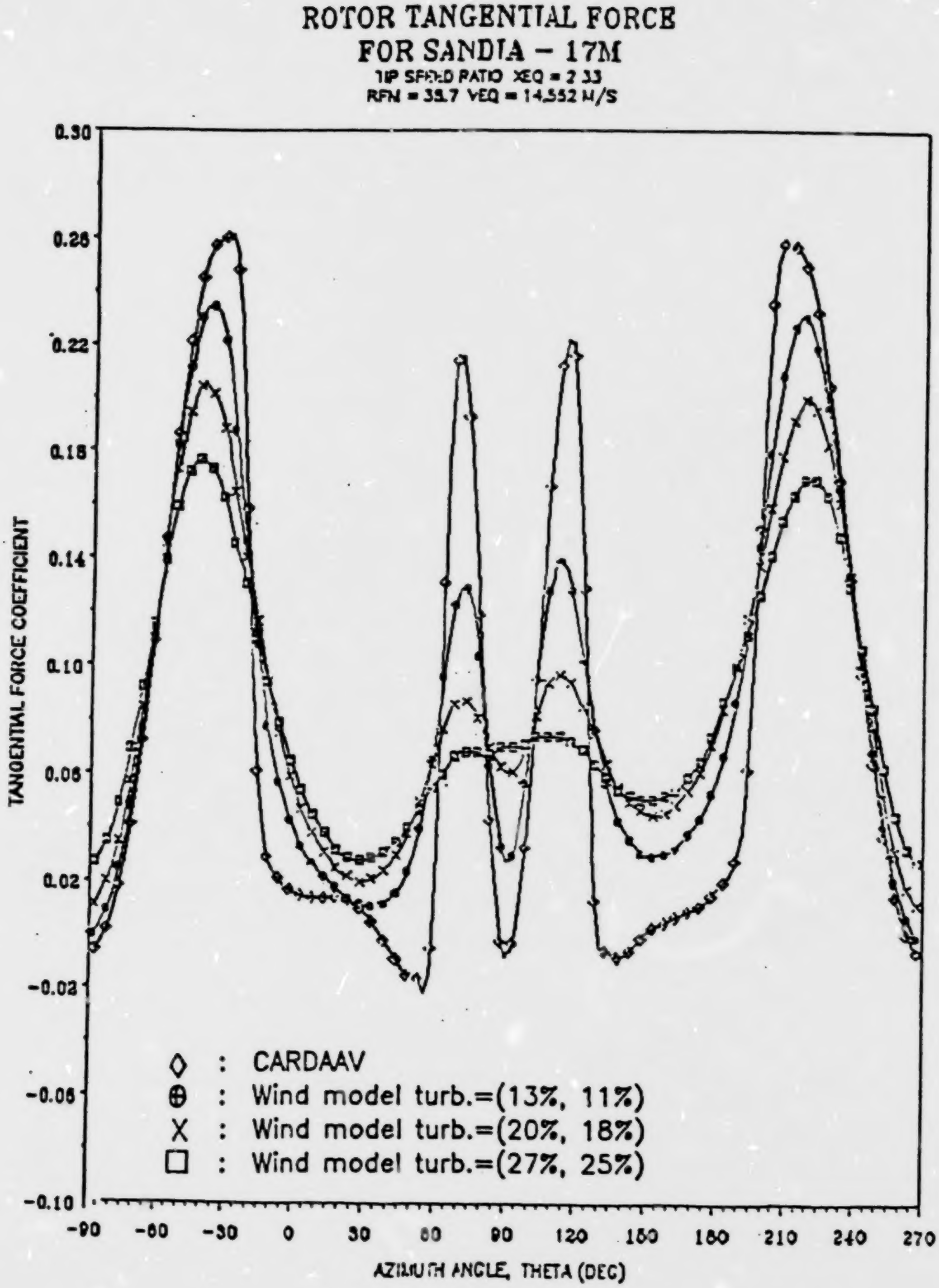


Fig. 14 Comparison of the tangential force coefficient at three intensity levels with CARDAAV results, at XEQ = 2.33

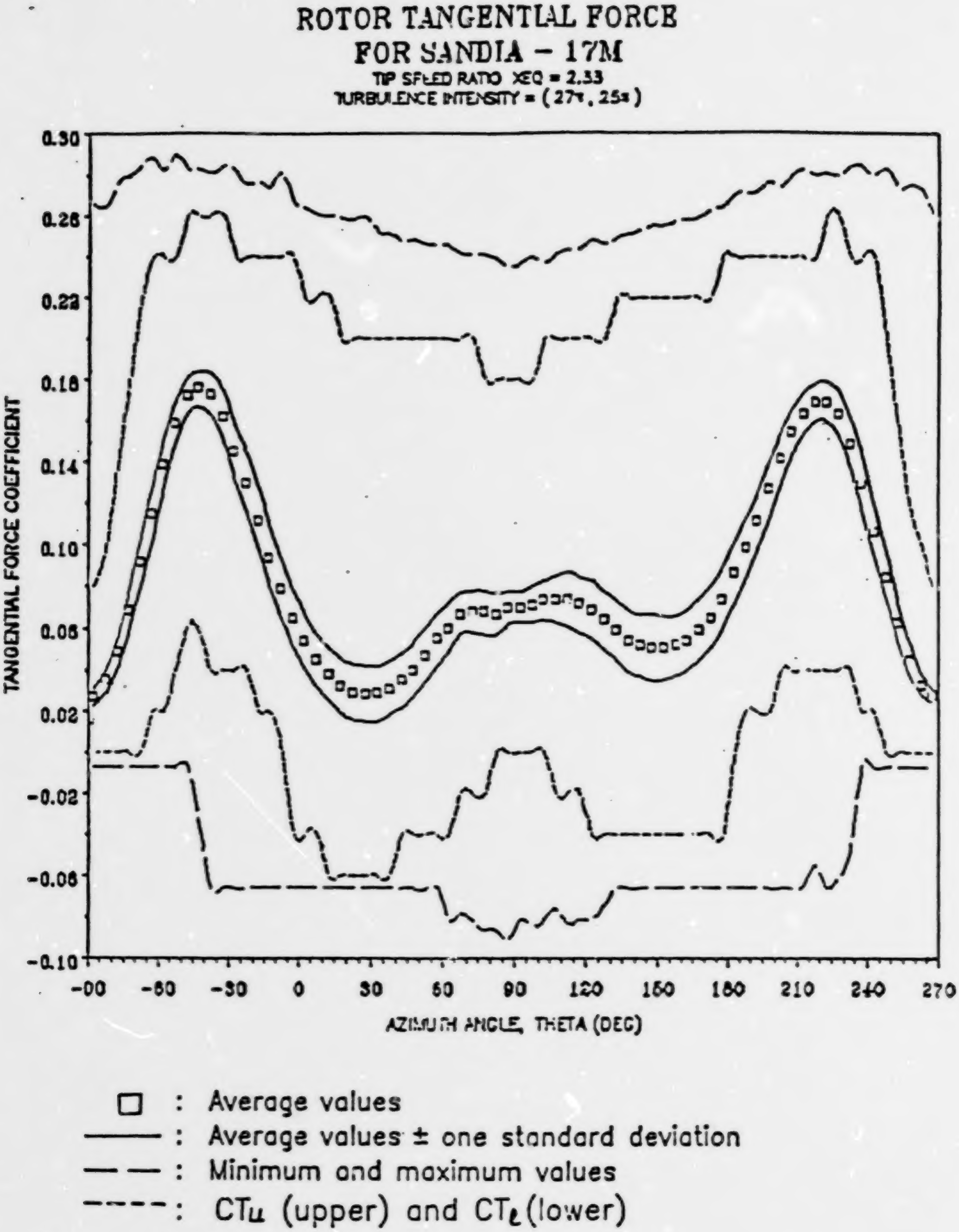


Fig. 15 Tangential force coefficient with a longitudinal and lateral turbulence intensities = (27%, 25%) and XEQ = 2.33

Wind Energy Program Overview

Presented at CanWEA 1987
Calgary, September 27-30

Monique Carpentier, P.Eng.
Technology Co-ordinator
Renewable Energy Branch
Energy, Mines and Resources Canada

Introduction:

Since May 1985, programs for research, development and demonstration activities have been administered by one group within EMR, the Renewable Energy Branch. The annual budget for the Solar Energy Division, which covers technologies such as active and passive solar, wind, small and low head hydro and photovoltaics, is in the order of \$12 M; \$6 M for R&D, of which approximately \$1 M is for wind energy, and \$6 M for demonstration projects. Within the demonstration program there is no preset funding level for wind energy projects.

R&D Program Update:

The primary goals of the wind energy R&D program are to encourage research, to establish a technology base, to support industry, and to confirm the viability of wind energy as an energy supply alternative. Twice a year, the Technical Advisory Committee (TAC), which is composed of representatives from research institutions, test sites and the industry, meet to establish specific priority areas for wind energy. The next meeting of the TAC will be held on October 22, 1987. At that meeting, the project results from last year's R&D activities will be evaluated and the priority areas will be redefined. This will enable us to prepare specific requests for proposals as required for the coming fiscal year. I hope that the CanWEA conference will provide a good forum for discussions between industry, TAC members and government representatives since such discussions are necessary to ensure that we keep each other "on track" during the development of this very promising technology. I am particularly pleased to see that 12 of the papers presented during this conference are research projects sponsored by our R&D program.

Once again in FY 1987/88, we have received more proposals and requests for funding than could be accomodated under the wind energy R&D program. From the Call made in late December 1986, 32 proposals requesting $11.2 M from EMR were received. The selection was not an easy task. We have since committed $1.1 M for FY 1987/88 toward 19 contracts. We have also been able, with the financial collaboration of the Unsolicited Proposals Program of the Department of Supply and Services, to increase this year's funding by another $650K. This extra funding will support multi-year projects for wind turbine developments incorporating unique characteristics.

One key feature of the wind energy R&D program for FY 1987/88 is the emphasis on cost shared projects with the industry. I am pleased to say that among the technologies funded by the Solar Energy Division the wind program is achieving the best cost sharing level for its R&D projects. In FY 1987/88 it is expected that the federal government, including the contribution from DSS, will provide about 53% of the total value of the wind energy R&D projects. This co-funding arrangement has proven to be very effective at a time of budget restraints and this partnership relationship seems to be well accepted by the industry. It is a healthy sign of our industry's seriousness in developing their products.

The R&D activities sponsored by EMR have been identified as priority areas by the industry to help them penetrate both Canadian and export markets. The most important current R&D directions are:

a) wind/diesel: two wind/diesel test beds have been established. The wind/diesel test beds are essential for the development of wind/diesel systems suitable to the Canadian remote community market and the export market. Due to the substantial funding requested to undertake such development, the federal support is viewed as essential. Several studies in the wind/diesel area are also underway.

i) The first test bed is at the Atlantic Wind Test Site in P.E.I. It was established during the summer of 1987 at a cost of $100 K and is available for joint projects with industry or research groups to conduct developmental work on WECS to meet the near term market in remote communities and stand-alone applications.

ii) The second test bed is located at the Institute de Research d'Hydro-Quebec, IREQ. It is designed to develop a high penetration wind/diesel system with no storage. This activity is initially directed toward the electric utility applications in remote communities. (Funding over the next 3 years: $390 K from EMR and $700 K from IREQ). Several studies on wind/diesel are also being supported.

b) testing stations: the WECS manufacturers have at their disposal two well equipped testing facilities that are financially supported by EMR. The test sites are the safest and most appropriate place to conduct the initial operational tests of a new wind system since it is the first prototype of a wind system that is most likely to experiment some problems.

i) the Lethbridge Wind Test Site (LWTS) tests wind turbines for water pumping. Special funding was provided this year to equip the site with a deep well pump simulator. (Funding from EMR will be 200 K over the next 3 years, and contributions from Alberta Agriculture and Alberta/Canada Energy Resources Funnd (ACERF) valued at $300 K over 3 years).

ii) The Atlantic Wind Test Site in P.E.I. tests wind generators. The long term agreement established by NRC in 1981 covers the operating deficit of the site up to a maximum of $200 K/year until 1991.

c) WECS development: development and improvement of medium scale WECS (150 kW, 350 kW and 500 kW) which incorporate innovative concepts such as external frame support, hinged blades, flexible struts and tapered blades have been financially supported. The two main contractors (manufacturers) are ADECON Energy Systems and Indal Technologies Inc. Federal funding is in the neighbourhood of $300 K/year and high cost-sharing is requested from the industry.

d) basic research: a limited number of studies on structural modelling of VAWTs and aerodynamic modelling of turbulent flow effects are being carried out. Funding FY 87/88: $50 K.

e) standards development: four sets of standards and guidelines have been issued by CSA with financial assistance from EMR. They relate to:

- Safety, Design and Operation Criteria
- Performance
- Interconnection to Electric Utility
- Siting Guidelines

These standards have proven to be useful as they are already being used by some electric utilities, when they write their interconnection policies. Standards historically increase the consumer's confidence and are used by the industry to promote their products. We hope this will also happen with wind energy systems.

These are the main activities funded by the R&D program for this fiscal year. You should note that some of the projects will run over a period of two to three years.

Demonstration Programs Update:

During the last year, several projects of importance were implemented under two EMR programs: the Remote Community Demonstration Program (RCDP) and Enerdemo.

These programs are meant to address the barriers that inhibit the commercialization potential of wind energy systems. The federal government has played an instrumental role in the development of most demonstration projects. Under Enerdemo, 5 projects have been supported since 1985 for a total federal assistance of about $350K representing 30% of the total project costs. Under RCDP, four projects were supported for a total federal contribution of approximately $896K, or 45% of project cost. The total project cost usually includes the cost associated with an extended period of monitoring and information transfer activities.

The 5 most recent and important demonstration projects are:

a) Kuujjuaq, Nouveau Québec: A 65 kW (Bonus, Denmark) wind turbine was installed in September 1986 and connected to the local Hydro Quebec power grid. The wind turbine has been specially adapted to withstand temperatures to -35°C. As of early September the turbine produced 45,000 kWh in 4,200 hours of operation, outperforming predictions. It is expected that the system will produce energy at a cost of 24¢/kWh which is much less than the current diesel production cost of approximately 55¢/kWh.

b) Fort Severn, Ontario: A 60 kW (Howden, U.K.) wind turbine was installed in the community of Fort Severn. After some delay the wind turbine was installed this summer. The system is now being commissioned and the official opening should take place during the third week of October.

c) Cambridge Bay, NWT: The Northern Canada Power Commission (NCPC) is installing a mini-windfarm consisting of four 25 kW (Carter, U.S.) wind turbines. The wind turbines will be integrated into the NCPC diesel grid. This is the first installation of this kind in Canada and probably the first windfarm ever installed north of the Arctic circle. The system will begin operating in October 1987.

d) Calvert Island, B.C.: A hybrid system composed of two 2kW (Northern Power System, U.S.) wind turbines, a photovoltaic array and a diesel generator will power a telecommunication radio site operated by the British Columbia Telephone Company. A 3 year payback is expected. A joint EMR/B.C. telephone workshop on the broader subject of power sources for an unattended site will take place during the first week of October in Vancouver.

e) Hall Beach, NWT: This project is to connect 2 wind generators to the NCPC grid in order to supply power to a nursing station. The wind generators (Aerowatt, France) being installed are expected to reduce the energy bill of the Department of Health and Welfare, currently about 54¢/kWh.

This was truly a year of achievements for wind energy. Several wind systems of importance were installed in most of the market sectors where wind has been identified as a viable energy alternative. During the next few years, operational data will be collected. I am confident that the results will prove that wind energy was indeed the appropriate choice and will open up the market to more, cost-effective, reliable installations.

Conclusion:

Within the next few weeks, a revised list of priorities for the wind energy R&D activities for the FY 1988/89 will be established. Industry's needs to penetrate the markets and its technology requirements, will of course be taken into consideration when drafting the next request for proposals. The industry representatives on the Technical Advisory Committee as well as myself should be your point of contact if you wish to provide input.

On September 30th and October 1st, in Ottawa, we will be hosting a couple of meetings as part of our collaboration with the International Energy Agency. Fifteen countries will be represented to discuss their respective R&D activities in wind energy and future collaboration. We expect these types of exchange will not only help avoid duplication of effort, but allow us access to knowledge gained by other countries. Moreover, the contacts can also help us develop export markets for our technology.

As a representative of EMR, I am pleased to see the high level of co-operation existing between my department and the wind energy industry. I hope to see this partnership continuing over the next few years so that together, we can develop wind energy as an economic and technically-effective energy option for Canada and abroad.

CanWEA'87 is a clear indication by the federal government, industry and provincial agencies and utilities that wind energy is making progress toward being a viable option.

COMMERCIALIZATION

MARKETING UNDER DIFFICULT CIRCUMSTANCES

AN ADDRESS

BY

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Box 1137, Okotoks, Alberta

FOR

THE CANADIAN WIND ENERGY ASSOCIATION

1987 ANNUAL CONFERENCE

Calgary, Alberta
September 29, 1987

MARKETING UNDER DIFFICULT CIRCUMSTANCES

Dale Johnson
Wind Power Inc.
Okotoks, Alberta

1. Introduction

Looking at the title of this talk, I had difficulty grasping the real problems associated with developing a business within this new wind/private power industry. I believe it would be more comprehensible and the real feel for these problems would come across better if the title were "Commercial Barriers".

Many of you are aware of the upcoming provincial public inquiry which is scheduled for October 5, 1987 which will be addressing the issues surrounding small power production. Today, you will definitely be getting a look at Wind Power Inc.'s submission to that inquiry.

This paper is based upon problems surrounding the business development of this new and emerging small power industry. Many first hand experiences recounted here are examples of small business attempting to develop within an existing framework designed specifically for monolithic utility organizations.

In order to understand the slow development in the alternate energy field, some understanding of attitudes of utility companies, government and bureaucracies is necessary.

As well as addressing development problems, this paper will also include some appropriate recommendations.

2. Utility Attitudes

Provincially speaking, a company which has held a monopoly position for the past 75 years operates from a position of strength. Profit, based on revenue requirements coupled with a guaranteed rate of return, is strong incentive for hindering competition. However, this fear of competition is not in the best interest of the rate payer.

2. Utility Attitudes (Cont'd.)

There is definitely animosity on behalf of SPP's. This animosity is born out of frustration and the frustration is born out of the indifference, disinterest and inertia displayed by utility companies. Utility complacency is again not in the best interest of the ratepayer.

Utilities continue to show thier disregard for ratepayers when they fail to negotiate in good faith with SPP's by investigating the possibilities of alternate generation, however remote the possibilities may seem.

Specific utility customer information requests go unanswered for months. Utility discussions and negotiations inevitably lead to further discussions and never to any firm commitment. Small business does not have the luxury of time and money to enter into lengthy negotiations that have no intention of solving the issues at hand.

3. Government Attitudes

Government's view has always been that SPP's should work with the utility companies and within the present bureaucratic system. Our recent provincial order-in-council regarding the small power inquiry only came about after government's realization that the present system is not structured to facilitate small energy producers.

Government's have traditionally been educated by utility companies. Therefore, when new and different possibilities for electrical generation are discussed, SPP's are faced with an already entrenched mental attitude. Additionally, conflict of interests seem apparent when elected officials eventually hold positions within utility companies upon their return to the private sector and/or own or control resources that may be required by generating utilities.

4. Bureaucratic Attitudes

Regulatory boards seem to have enough of their own problems without voluntarily getting involved with new issues. Generally speaking, they also have been of the opinion that SPP's should deal directly with utility companies. Bureaucrats insist that the present system works just as well for small

4. Bureaucratic Attitudes (Cont'd.)

producers as for the large utilities, however, there are many times when mediation is required.

I believe the "system" is just beginning to realize that small power producers are serious about this new industry. As a result, jurisdictional problems between boards arise because there are no categories in which one can slot SPP's.

Regulatory boards are also heavily influenced by utility companies. In most cases, utilities are the only source of information for these boards and, in some cases, board members end up in the employ of utility companies.

5. Summary

Small business and business development in this new industry has been delayed by the indifference and tardiness of the government and utility companies.

Utility self interest must not continue if the ratepayer is to be the beneficiary of the greatest results possible from a more reliable and cost effective electrical system. Confidentiality of information such as utility contracted fuel purchases impact the ratepayer and, therefore, must be made available to the ratepayer to make accurate business decisions.

If the utility companies are as cost effective and service is as reliable as possible, the opportunity of legitimate competition from private power should not pose a problem.

Any limited success achieved during negotiations with the utility companies has been negated by confused regulatory bodies who have unclear jurisdictional guidelines. The loss of additional WECS installations has been the result. The small power industry lacks influence but does not lack the knowledge which will benefit ratepayers.

Each resource has it's own unique drawbacks - each also has it's own unique positive characteristics. Individually, these resources all have something to contribute; collectively they can enhance, stabilize and improve the reliability of the electric system. This building together will eventually reduce reserve margin capacities, thus benefiting the ratepayer.

The wind industry does not want or need the tax credit problem of the United States. Although there was nothing wrong with the basic idea - the program was implemented, administered and withdrawn improperly. There have been tax credits around for many years but they are most effective when an "even keel" approach is taken.

6. Conclusions and Recommendations

The existing utility system is built upon the wrong principles. Utility revenue requirements plus a guaranteed rate of return and provincial debt guarantees do not embrace economic restraint - they encourage waste. We are all familiar with the inefficiencies of very large organizations. More jobs are created and efficiency thrives when small business thrives. Utility contractual confidentiality can only be acceptable within a competitive system. A competative atmosphere in the electric generation industry will benefit the ratepayer.

Government must take the initiative, lay the foundation and establish a framework which is condusive to creating an atmosphere which will nuture this new industry. This can easily be done within existing legislation but it is necessary that a policy be outlined and displayed.

Expeditious procedures for private power producers means growth in regional and local communities. Blanket board exemptions for non-utility owned generation should apply. Applications should remain simple. Regulation of rates would not be a significant issue if there was competition within industries which have traditionally been considered sacred.

Regulatory boards and/or utilities would do well to have on staff, or at least at their disposal, a consultant from the private power sector to contribute expertise in building a more efficient inter-connected system. This could possibly be co-ordinated with or through the many SPP organizations springing up across the country.

Wind turbine sales have come about as a result of the tenacity and persistence of both purchasers and developers. The Small Power Producers Association of Alberta is playing an integral role in persuing all government and regulatory avenues to facilitate changes in the Alberta system.

National and international goals for energy development are clear. Environmental issues are a top priority and the advancement of renewable resources and the efficient use of our non-renewable fuels is in the forefront of development. It is hoped that Canada will rise to the challenge of a more diversified resource base.

VAWT ACTIVITIES AT FLOWIND

L. Schienbein
Director of Engineering

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94566

Presented at the
Canadian Wind Energy Conference '87
Calgary, Alberta
September 27-30, 1987

OUTLINE

- FLOWIND WINDFARMS/ENGINEERING
- VERTICAL AXIS WIND TURBINE PERFORMANCE
- RESEARCH AND DEVELOPMENT ACTIVITIES
- SUMMARY

FLOWIND WINDFARMS/ENGINEERING

CALIFORNIA WIND FARMS
TURBINES OPERATED BY FLOWIND

Type	Number Installed Tehachapi	Altamont	Total
FloWind 19M VAWT	180	21	201
FloWind 17M VAWT	161	148	309
FloWind 25M VAWT	2	--	2
Danwin 110	--	25	25
Bonus 120/20	--	200	200
Bonus Mark III	--	100	100
Bonus Mark II	--	25	25
Total	343	519	862

WIND FARM SITE CHARACTERISTICS

Parameter	Tehachapi Property	Altamont Pass Property
Mean Wind Speed	18 mph	15 mph
Annual Wind Distribution	Rayleigh (approx.)	"Altamont" Type
RMS Turbulence (Free Stream) at 40 mph.	15 to 20% (estimate)	15% (estimate) *
Wind Shear Power Law Exponent	0.15 to 0.20	0 to 0.1 *
Average Annual Density	0.86	0.98
Sustained Winds > 60 mph	Frequent to 80 mph. Gusts in excess of 100 mph recorded.	Rare. Perhaps one event each year at best sites.
Icing	Two or three events each winter. Severe.	None
Bug and Dirt Effect	Not well established. Believed to be less important than Altamont.	Effect on 19 M VAWT has been measured. Rain washing seems effective on that turbine.
Terrain	Complex ridge with major plateau. Rough. Steep upwind edge.	Rolling hills wth some pronounced ridges across prevailing wind direction. No trees. Grassland.
Turbine Spacing	About 75% of the turbines are in geometric arrays of up to 5 rows deep. Same minimum spacing as Altamont.	Mostly linear following ridgelines. Some two and three row arrays. Minimum spacing is 3 diameters across wind and 7 diameters downwind.

* Limited Data

FLOWIND ENGINEERING TASKS

- Support Operations and Maintenance to decrease turbine maintenance costs, increase availability and increase energy output.

- Complete the design and testing of structural retrofits for the 17 and 19 meter VAWTs.

- Develop and implement a turbine structural life management plan in co-operation with operations and maintenance.

- Upgrade the 19 meter VAWT design in co-operation with CENEMESA to increase reliability and fatigue life and reduce production costs. Goal is $0.20/kWh ratio of installed cost to annual output for California wind farms.

- Design, build and test an optimized rotor for the 19 meter turbine to decrease the cost of energy and increase rotor fatigue life.

VERTICAL AXIS WIND TURBINE PERFORMANCE

FLOWIND VERTICAL AXIS WIND TURBINES

ELECTRICAL ENERGY OUTPUT

	APPROXIMATE TOTAL OUTPUT (kWh)	DATE
Tehachapi	150,000,000	Through 9/24/87
Altamont	90,000,000	Through 9/24/87
TOTAL	240,000,000 kWh	

FLOWIND VAWT OPERATING
HOURS TO SEPTEMBER, 1987

19 METER TURBINES
41 Installed in 1984

Operating Hours	Percent of Fleet
> 8,000	78%
> 9,000	59%
> 10,000	44%
> 11,000	17%

160 Installed in 1985 have operated between 4600 and 8000 hours.

FLOWIND

19 METER VERTICAL AXIS WIND TURBINE

SAMPLE PERFORMANCE

Swept Area	316 m^2
Cut-out	60 mph (26.8 m/s)
Rated Output at Cut-out	267 KW (Tehachapi)
Rated Output at Cut-out	306 KW (Altamont)

SITE	TURBINE #	RUN HOURS	AVG. POWER	$\frac{\text{AVG. POWER}}{\text{SWEPT AREA}}$
T	451	6160	114.8	0.36
T	143	9701	97.4	0.31
T	331	6986	82.6	0.26
T	165	6817	71.8	0.23
A	114E	11,135	115.6	0.37
A	119E	11,270	92.4	0.29
A	118E	10,668	84.2	0.27

17 METER TURBINES

309 Turbines installed in 1983, 1984 and 1985

Operating Hours	Percent of Fleet
> 16,000	1.9%
> 15,000	9.1%
> 14,000	19.7%
> 13,000	23.3%
> 10,000	50.2%

RESEARCH AND DEVELOPMENT ACTIVITIES

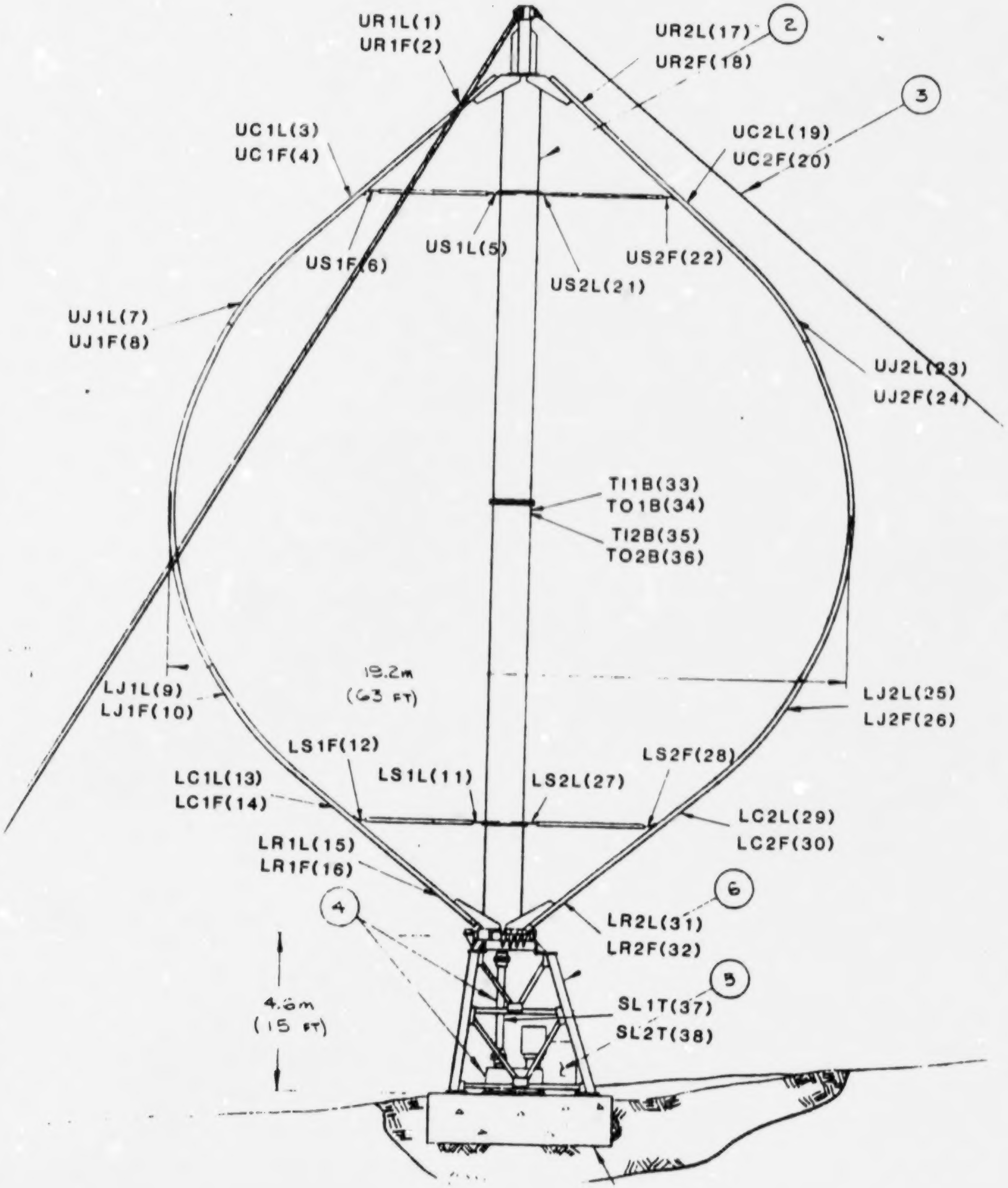
TESTING - STRUCTURAL RESPONSE AND PERFORMANCE CHARACTERIZATION

- 17 AND 19 METER DATA ACQUISITION, TEHACHAPI 1985-86.
  - POWER OUTPUT PERFORMANCE
  - STRUCTURAL RESPONSE - OPERATING
    - START/STOP
    - PARKED (HIGH WIND)
  - AUTO-ORIENTATION/SELF STARTING
  - ICING EFFECTS

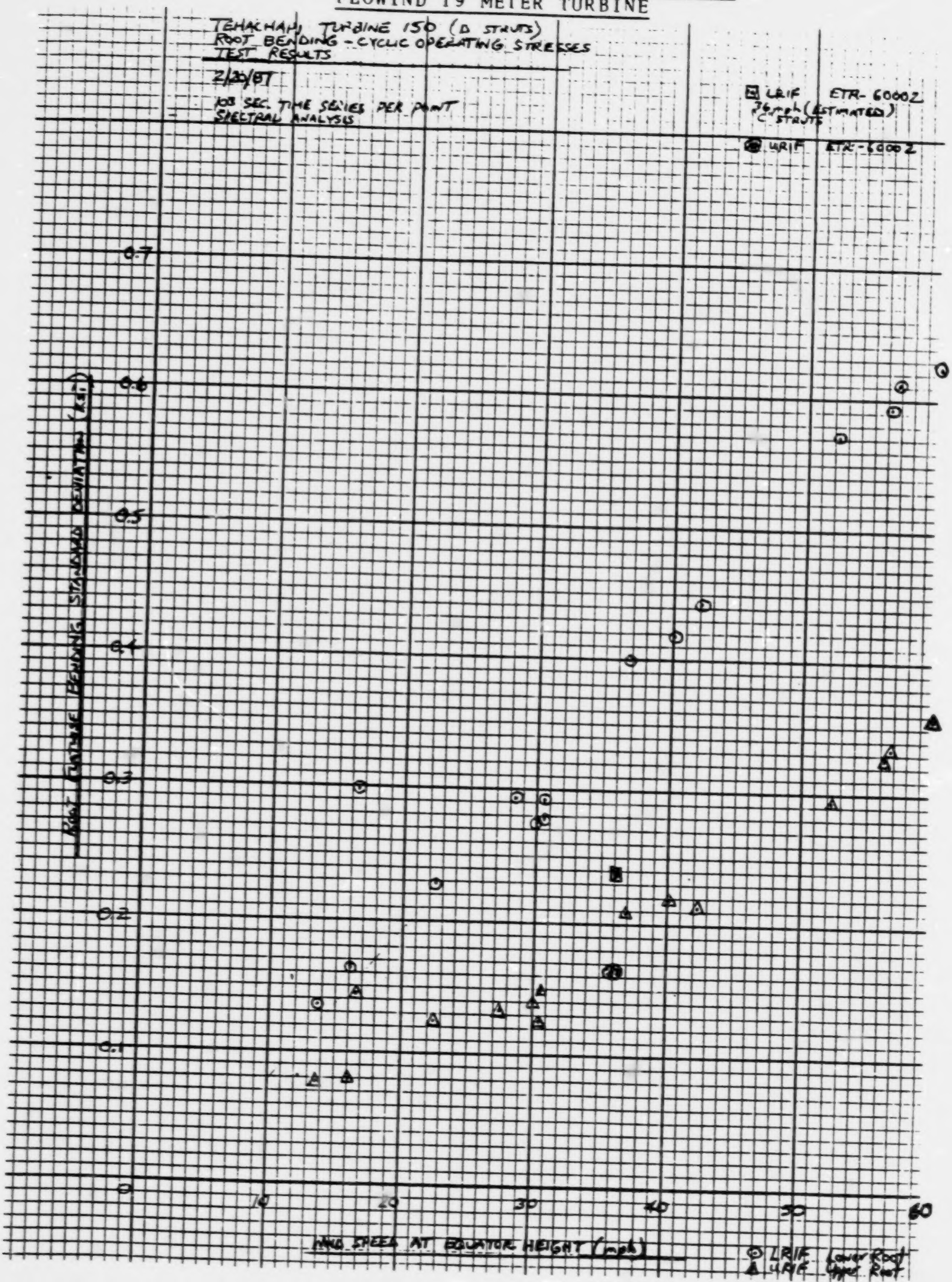
19 METER TURBINE TESTING

- STRUCTURAL LOADS DATA ACQUIRED DURING OPERATION FROM CUT-IN TO 60 MPH.
- PARKED STRUCTURAL RESPONSE FOR 30 DEGREE POSITION INCREMENTS.

FloWind 19 m Strain Gauge Locations, Designations & Numbers


UR1L(1)
UR1F(2)
UR2L(17)
UR2F(18)
2
3
UC1L(3)
UC1F(4)
UC2L(19)
UC2F(20)
US1F(6)
US1L(5)
US2F(22)
US2L(21)
UJ1L(7)
UJ1F(8)
UJ2L(23)
UJ2F(24)
TI1B(33)
TO1B(34)
TI2B(35)
TO2B(36)
LJ1L(9)
LJ1F(10)
19.2m
(63 FT)
LJ2L(25)
LJ2F(26)
LS1F(12)
LS1L(11)
LS2L(27)
LS2F(28)
LC1L(13)
LC1F(14)
LC2L(29)
LC2F(30)
LR1L(15)
LR1F(16)
6
4
LR2L(31)
LR2F(32)
5
4.6m
(15 FT)
SL1T(37)
SL2T(38)

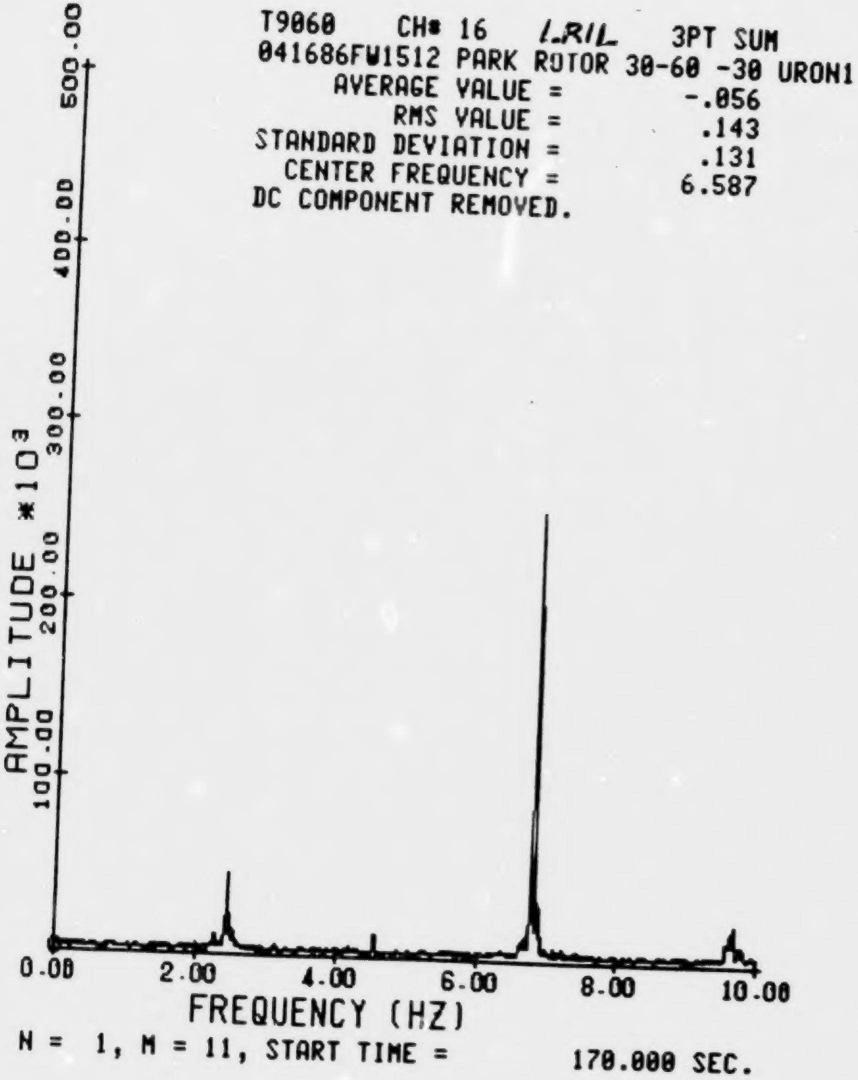
BLADE ROOT BENDING CYCLIC STRESS DATA
FLOWIND 19 METER TURBINE



19 METER TURBINE
PARKED STRUCTURAL RESPONSE EXAMPLE

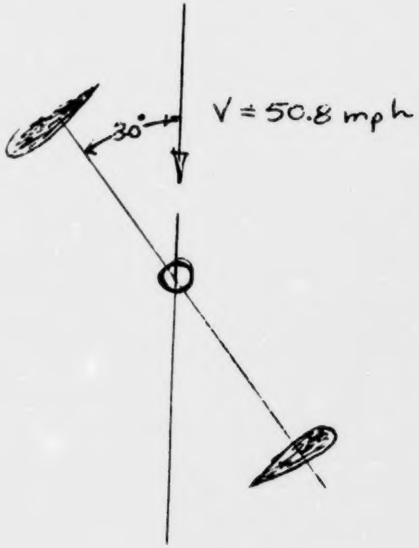
- SIGNIFICANT LEAD-LAG RESPONSE AT 6.8 Hz. for the rotor oriented as shown (30°). Average wind speed was 50.8 mph. (Response recorded on video tape.)
- FEVD predicts second propeller mode at 7.08 Hz.
- Simple Strouhal Number vortex shedding calculation gives shedding frequencies of between 4.2 Hz and 6.9 Hz for 25 to 35 degrees and wind speeds of 40 to 60 mph.
- Cyclic Stress Data

Location	Standard Deviation	Center Frequency	Equivalent Operating Wind Speed (approximate)
Lower Blade Root (LRIL) Lead Lag	131 psi	6.6 Hz	50 mph
Lower Blade Root (LRIF) Flatwise	149 psi	4.2 Hz	15 mph
Upper Blade to Blade Joint Lead Lag (UJIL)	244 psi	6.8 Hz	45 mph
Upper Blade to Blade Joint Flatwise (UJIF)	221 psi	3.2 Hz	25 mph
Lower Strut to Blade Connection Lead Leg (LCIL)	564 psi	6.8 Hz	30 mph
Upper Strut to Blade Connection Flatwise (UCIF)	283 psi	3.6 Hz	15 mph



```
T9060    CH# 16    LRIL    3PT SUM
041686FW1512 PARK ROTOR 30-60 -30 URON1
      AVERAGE VALUE =            -.056
          RMS VALUE =             .143
 STANDARD DEVIATION =             .131
   CENTER FREQUENCY =            6.587
DC COMPONENT REMOVED.
```

N = 1, M = 11, START TIME = 170.000 SEC.

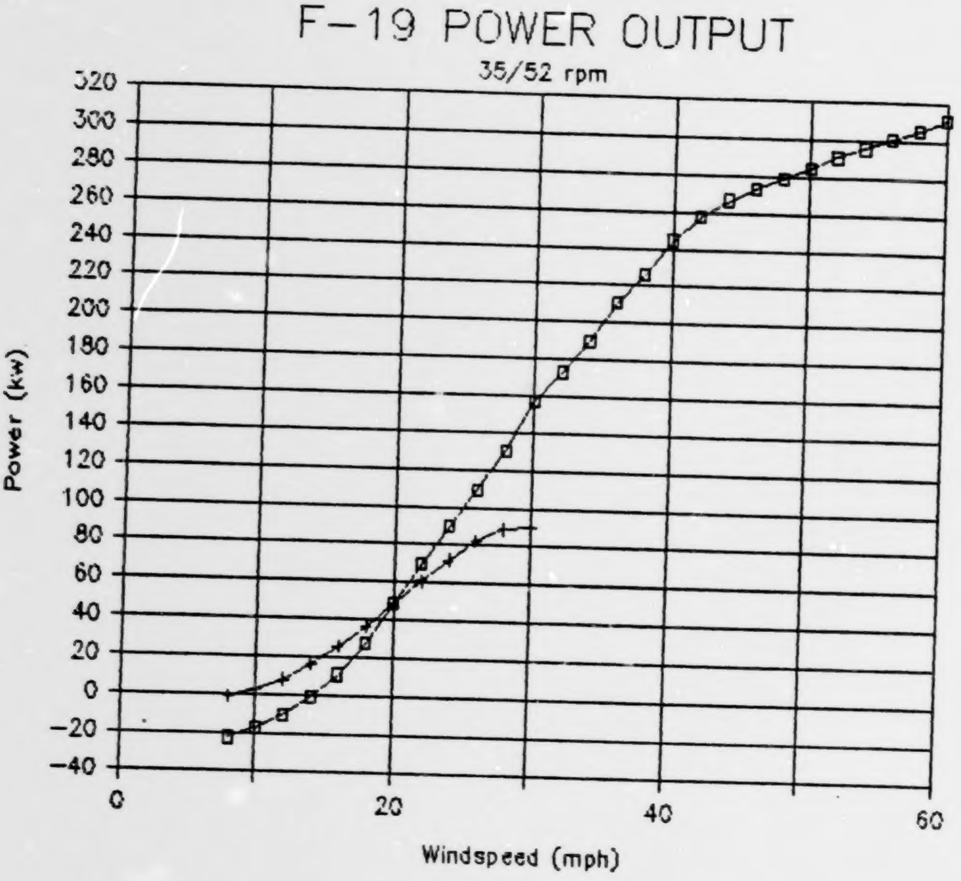


ROTOR ORIENTATION

PERFORMANCE IMPROVEMENTS

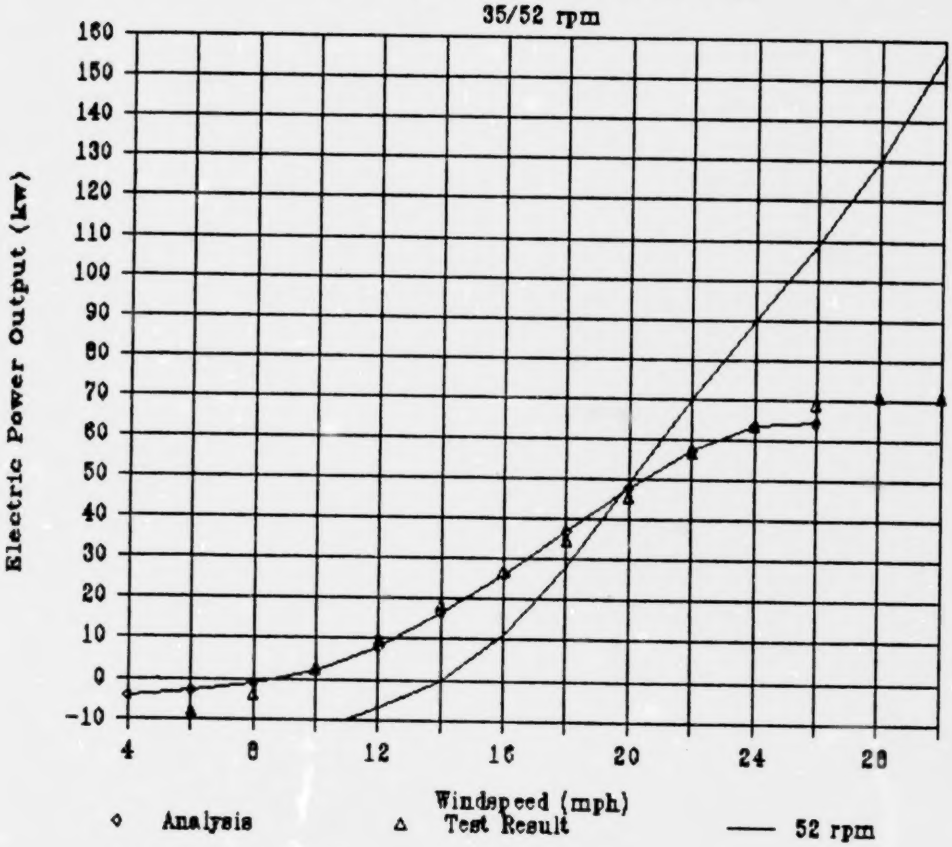
- 19 METER TWO SPEED OPERATION - TEHACHAPI, 1986
  - 26/52 RPM
  - 35/52 RPM
- VORTEX GENERATORS - 19 METER TURBINES
- EFFECT OF DIRTY BLADES

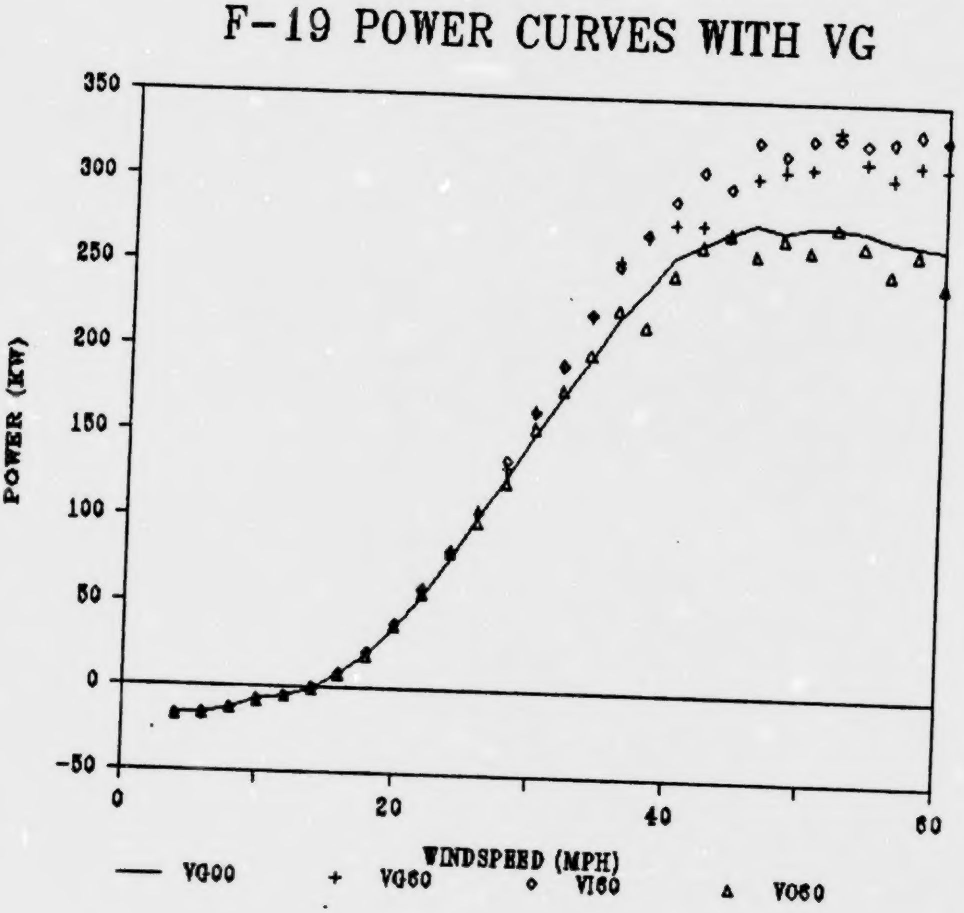
FLOWIND 19 METER TURBINE TWO SPEED OPERATION MEASURED PERFORMANCE



F-19 POWER CURVE

35/52 rpm



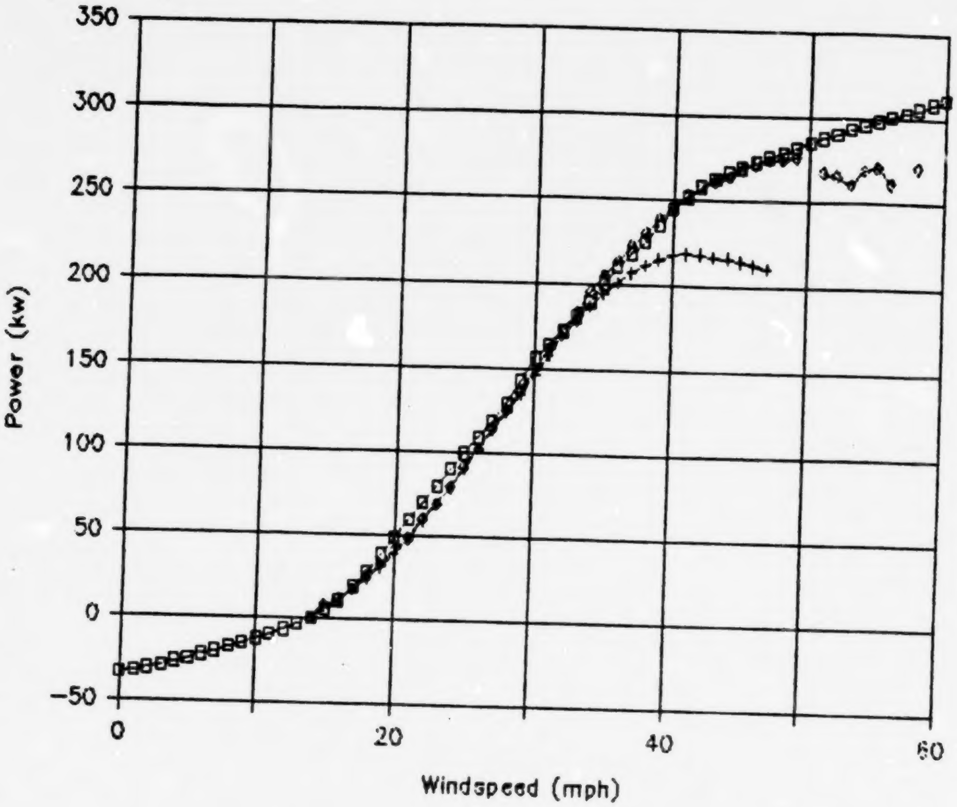


Performance Predicted by the DMST Program Using a Power Loss Model

APPLICATION OF VORTEX GENERATORS TO THE 19-METER WIND TURBINE SAMPLE PREDICTED PERFORMANCE EFFECTS

MEAN WIND SPEED (mph)	% OF BLADE LENGTH WITH VORTEX GENERATORS	SIDE OF BLADE	PERCENT INCREASE IN ENERGY OUTPUT (19-METER BASELINE)
16	40%	Both sides	3%
		Inside only	4%
16	60%	Both sides	7%
		Inside only	8%
		Outside only	< 1%

FLOWIND 19 METER TURBINE
EFFECT OF BLADE WASHING ON TURBINE PERFORMANCE



□ Official 19 Meter Power Curve
◇ Measured Output with Clean Blades (PG and E Data)
✚ Measured Output with Dirty Blades (PG and E Data)

PREDICTED ANNUAL ENERGY LOSS DUE TO DIRTY BLADES FOR VARIOUS ALTAMONT WIND DISTRIBUTIONS

Site	Annual Output (Clean Blades)	% Loss with Dirty Blades
Reference (R=1)	625,000 kWh	7
R=0.9	499,000	5
R=0.8	371,000	3
R=0.7	250,000	2

TURBINE DEVELOPMENT

- DESIGN, DEVELOPMENT AND TESTING OF AN OPTIMIZED TURBINE (23/300 VAWT)

- ANALYTICAL MODEL DEVELOPMENT AND IMPLEMENTATION - STRUCTURAL DYNAMIC LOADS, NATURAL FREQUENCIES AND MODE SHAPES, PERFORMANCE AND BLADE DESIGN, FINITE ELEMENT METHODS TO SUPPORT DESIGN OF STRUCTURAL DETAILS, CRACK GROWTH ANALYSIS, CONTROL LOGIC SIMULATION.

- ADVANCED VERTICAL AXIS WIND TURBINE

  - KEY TECHNOLOGIES AND CONCEPTS ASSESSMENTS

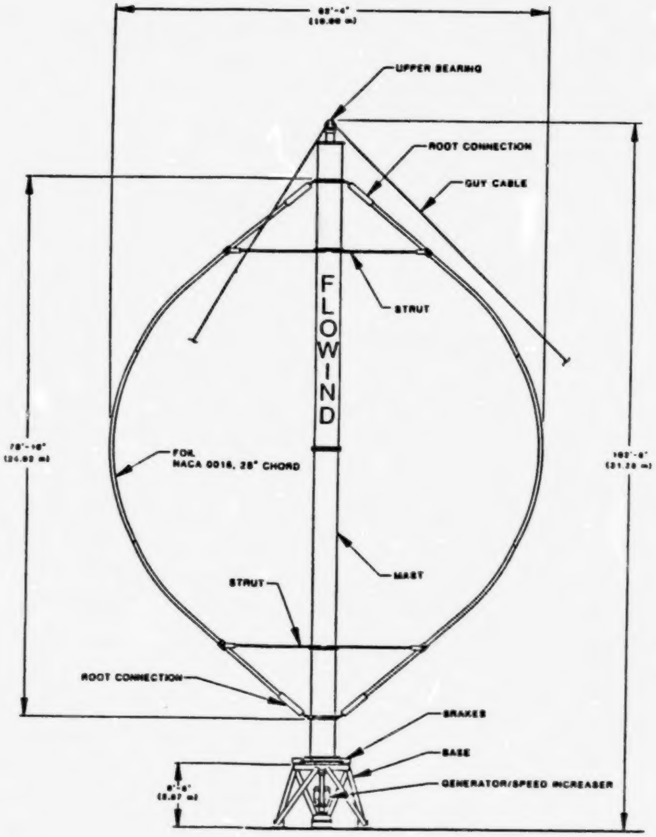
VAWT ROTOR OPTIMIZATION USING THE SNLA 1850

EXAMPLE

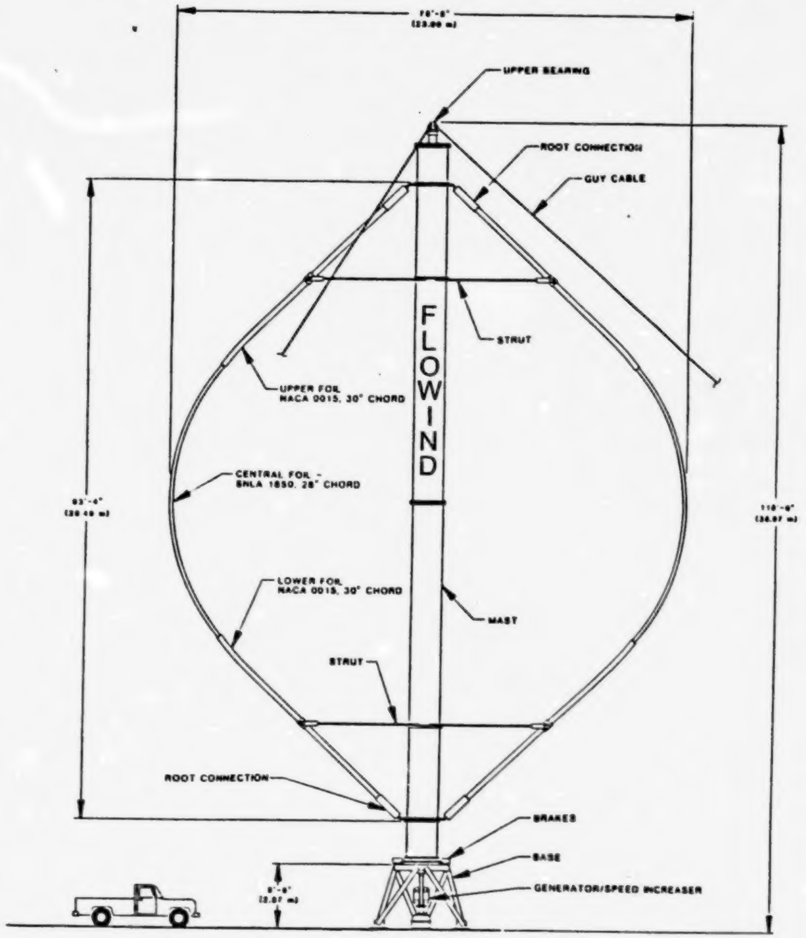
CONFIGURATION II (Model 23/300)	30" NACA 0015 Root Sections 28" SNLA 1850 Equator Sections Rotor Height - 93'-4" Diameter - 75'-5" (23 M) 50 RPM Generator Rated Power 275 kW (approx.)

AVERAGE WIND SPEED *	PREDICTED INCREASE IN ANNUAL ENERGY OUTPUT (existing FloWind 19M is reference)	PREDICTED ANNUAL OUTPUT (kWh)
14 mph	26%	400,000
15.3	25%	491,000
16.8	21%	618,000

* "Altamont" wind distribution


62'-4"
(19.00 m)
UPPER BEARING
ROOT CONNECTION
GUY CABLE
STRUT
FLOWIND
78'-10"
(24.02 m)
FOIL
NACA 0015, 28" CHORD
102'-4"
(31.20 m)
MAST
STRUT
ROOT CONNECTION
BRAKES
BASE
6'-9"
(2.07 m)
GENERATOR/SPEED INCREASER

MODEL 19/250


75'-5"
(23.00 m)
UPPER BEARING
ROOT CONNECTION
GUY CABLE
STRUT
FLOWIND
UPPER FOIL
NACA 0015, 30" CHORD
CENTRAL FOIL –
SNLA 1850, 28" CHORD
93'-4"
(28.45 m)
118'-4"
(36.07 m)
LOWER FOIL
NACA 0015, 30" CHORD
MAST
STRUT
ROOT CONNECTION
BRAKES
BASE
6'-9"
(2.07 m)
GENERATOR/SPEED INCREASER

MODEL 23/300

FLOWIND CORPORATION
ADVANCED VERTICAL AXIS
WIND TURBINES

SUMMARY

OBJECTIVES OF THE VAWT RESEARCH AND DEVELOPMENT ACTIVITIES AT FLOWIND

- IMPROVE THE EXISTING 17 AND 19 METER TURBINES - PERFORMANCE, STRUCTURE AND RELIABILITY.
- UPGRADE THE 19 METER VAWT DESIGN. INCREASE PERFORMANCE AND RELIABILITY. REDUCE MANUFACTURING COSTS.
- DESIGN, BUILD AND TEST AN OPTIMIZED VERTICAL AXIS WIND TURBINE BASED ON THE 19 METER UNIT (23/300 DESIGN).

BUSINESS PANEL

WIND ELECTRIC USERS PERSPECTIVE

Ernie Sinnott

We are the users of a Wind Electric plant that was installed February 1st 1984 and operated very satisfactorily ever since.

Our operation consists of a fairly large farm and Agro-Business that uses quite a bit of power.

I might say that due to the Banking Concept that the Energy Resources Conservation Board awarded us that same year, we have not purchased any power since the machine started.

The machine is an Enertech model 44-40-3 phase that puts out 480 volts with a capacity maximum of 45 (kw) kilowatt. It is on an 80 foot self supporting tower and is interconnected with Transalta Utilities. The rotor or propeller is three bladed, 44 feet in diameter and operates on the leeward side of the tower. It has no tail or vane to hold it into the wind. The blades are mounted in what I would call a convex shape that automatically holds it into the wind. It only turns at a speed range of 54 to 57 (r.p.m.) revolutions per minute so it does not make a large amount of noise. It has tip brakes on every blade that only come into play if for some reason the rotor goes into an overspeed. The speed is controlled by what the Enertech Company calls a dynamic brake or other words,electrically.

We have had no trouble to amount to anything. The maintenance has been very little consisting of one oil change of the transmission per year. The machine does not show any wear and should run for 20 to 25 years with some overhauls. Assuming this, it should be a very worth while investment especially in our part of the world where we get a large amount of wind.

In addition to the power used in the farm shop and feed yard, we have two dwellings and a mobile home. The business is mainly fertilizer blending and pumping, as well as farm chemical distribution.

I think that wind power should be used more extensively in this part of the country due to the fact it is renewable and a non-polluting resource. The wind is far from comfortable some times, but if you can make good use of it a person would feel much better about it.

CANWEA CONFERENCE

ENVIRONMENTAL PROTECTION IS MORE THAN GOOD ETHICS - IT IS GOOD BUSINESS

Susie Washington, President
Western Environmental and Social Trends

Concerns for the environment have risen quickly to a prominent spot on Canada's public agenda. The nascent concerns of the 1960's and 70's which, with rare exceptions, were held and expressed by individuals or small groups have mushroomed. Today, concern for our environment has become a compelling part of Canada's value system. The extent of the public's environmental concern is born out by a recent Decima poll (summer '87). When asked what comes to mind when thinking about the environment, eight out of ten people identified an environmental problem, not a positive aspect of the environment.

Environmental protection, as understood by Canadians, is now a leading social issue. It is evident in health and safety concerns at the local level, acid rain initiatives at the national level and even expresses itself at the international level, where debt reduction assistance to developing countries is often conditional on protection of significant natural areas in the recipient country.

As environmental pressures mount nationally in response to a broadly-based and important social trend, governments at the federal, provincial and municipal levels are responding with tough new legislation and regulations. Of immediate importance to the resource sector are:

- The proposed Canadian Environmental Protection Act, now before parliament. It provides for $1 million/day fines for offending companies, and jail sentences of up to five years for their senior managers.

- A review of Alberta's environmental legislation with the intent of revising the Clean Air and Clean Water Act to close exsisting loopholes in the law, and to enable enforcement. This review may lead to an environmental police force for the province.

- Hazardous Waste legislation which has been tabled in Alberta for review, covers the life cycle of a variety of chemicals with the option for more stringent regulations to be phased in.

- In B.C., South Moresby has been declared a national park with explicit recognition of both the marine and land eco-systems as integral parts. A co-management plan is to be instituted with the Council of Haida Nations.

- The Federal Environmental Assessment Review Office is planning to table a white paper this fall that proposes to legislate the environmental review procedure for resource development projects on all federal lands.

Considered in aggregate, this resurgence of new environmental legislation, the review of existing regulations, and the current trend to protect significant lands is a clear signal of new and more stringent regulatory climate for doing business in the resource sector, particularly the energy sector.

While scientific and technical solutions provide part of the answer in these complex new challenges, it continues to be difficult for untrained or inexperienced managers to deal with the people side of the equation. Yet public attitudes and perceptions about environment and risk are legitimate concerns which must be considered early in energy project planning.

If impacted and interested parties are not consulted in an appropriate and timely manner, development projects are likely to become stalled in what may well become a regulatory nightmare. Given the new environmental protection mood of the country, economic benefits alone no longer seem enough to secure support for projects which impact on the public.

You may be thinking that yes, I agree with what she is saying, but how does that apply to wind power which is a renewable resource?

The potential environmental, ecological and socio-economic effects of large scale use of renewable resources such as wind power are to a large extent unkown. However, direct land effects are highly dependent upon the situation in which technolgies are used. In other words, arrays of wind power generators have the potential to emulate the land displacement effects and some of the socio-economic impacts of non-renewable resource industries if not managed appropriately.

Notwithstanding potential effects, your industry has the immediate challenge of becoming more competitive in an era of environmental protectionism, with the resulting concern for energy efficiency and conservation. One important option that is frequently overlooked is to build a strong coalition of trusting friends by establishing openness and a credible track record with respect to environmental issues.

The art of coalition building involves four important steps:

1. Look for "industry friends" - it's often easier to make change happen, and involve other outside interests with the support of one or more industry associations.

2. Identify the advocacy and community groups who might consider themselves to have an interest in your industry. Don't necessarily exclude groups that have opposed you in the past, or whom have already indicated they intend to oppose you on the upcoming issue.

3. Brainstorm and prepare an action plan that involves making your company's or industry's concern known to a core group of credible third parties from the range of interested parties you have identified. The purpose of this step is to identify potential common interests or new vulnerabilities around your company's position.

4. Be ready to extend every courtesy to those organizations whom you have identified as opposing your industry. Here your goal is to gain a new perspective on where you may be vulnerable and to build an informed opposition. That is opposition that is based on substance, and one that is based on mutual respect rather than personal animosity.

I would like to leave you with the thought that today, many resource development industries recognize that it is not just good ethics but also good business to protect the environment, and one of the best ways to achieve this is through effective coalitions.

THE TAX PERSPECTIVE

J.C. Shepherd

This year's conference is notable for the business-oriented atmosphere, not only in the sessions themselves, but particularly in the coffee breaks and in the trade show, where the number of business deals going on is striking. It is gratifying to see this evidence of the strides our industry has taken in just a few short years, and it is perhaps fitting that this year's conference should culminate with a business panel.

I am here to speak about tax issues affecting our industry. I will deal with them in two areas: first, a discussion of the two main tax breaks available in wind energy projects; and second, some brief comments on the impact of Tax Reform.

Tax Incentives for Wind Energy

There are two main tax incentives available for wind energy projects: Class 34 writeoffs for wind installations acquired as part of a business activity, and research and development credits and deductions available for activities at earlier stages. Despite the fact that these are very valuable tax incentives, the wind industry is not utilizing them to any great extent. In an industry where the economic viability of many of its players is marginal at best, it is amazing that these significant government funds, available literally for the asking, are not being tapped with more alacrity. I would like to explore briefly some of the reasons why this is the case.

Let us deal first with Class 34. There appear to be four reasons why the use of Class 34 is as sparse as it is.

The first reason is a technical one. Although effective from February, 1986, Class 34 availability for wind energy installations is still not technically available. The process is proceeding in Ottawa, and we are being assured again and again that wind turbines will be added to the Class 34 list in due course, but it is probably still a few months off. When enacted, this will be retroactive to February, 1986, and it should be made clear to everybody in the industry that this incentive can be used now as if it were the law. Therefore, the technical issue here is really not a barrier of any import to utilization of this incentive.

The second reason why Class 34 has not been used more often is undoubtedly the most critical. The wind industry has simply not been aggressive in going after this tax benefit. This should be understood in perspective. At the present time, the Class 34 benefit is economically equivalent to a cash grant of between 40 and 45 cents on the dollar against the cost of a wind installation. Despite the fact that this is really serious money, and could make or break many projects, I am constantly amazed to find people in the industry who don't even understand the most rudimentary aspects of this benefit. People who have taught themselves all of intricacies of how to get government grants of relatively small amounts have not taken the trouble to understand this, an almost unlimited source of funds for those who care to use it. Frankly, if we in this industry are not willing to spend the time to understand how we can get this money, then it serves us right if we can't make the money flow freely. My feeling is that people in the industry should be educating themselves in this area as a top priority.

Another aspect of market resistance to Class 34 lies in the peculiar psychology of the tax community. By this I do not mean the tax lawyers and tax accountants primarily, but rather the (what I would call) "shooters" who make it their business (and a very lucrative one indeed) to design and implement creative tax-based financing transactions. That group has not been excited by Class 34 as yet. In part this is because the people in the industry have not tried to get them excited. In part also it is because of the dampening effect of our problems with utilities, problems with governments, etc. We can assist in overcoming this problem by making ourselves more available to the tax community and to the brokerage industry, and by showing them thoughtfully conceived, thoroughly designed projects to which they can apply their creative instincts. That is starting to happen in Ontario now with small hydro, and there is no reason why the wind industry cannot have the same market penetration if it approaches this sector in the right way.

The fourth and most nebulous of the barriers to full utilization of Class 34 is the sophistication and complexity involved in the design of vehicles for tapping Class 34 in those situations where purchasers are not business people or are not taxable. A large number of the sales of wind energy installations in Canada are to municipalities, non-profit organizations, and governmental bodies. Because those entities do not pay tax, the Class 34 benefit is lost. It is axiomatic in tax planning that a tax benefit inherent in a transaction can almost always be tapped, one way or another, even if in the structure of the particular transaction it would otherwise be unavailable. The industry has not to my knowledge made any attempt whatsoever to try to convert the tax benefit associated with sales to non-taxable entities into cash. This is because doing so is complicated and difficult. However, given the amount of money involved it seems to me to be irresponsible not to put considerably more effort into accessing this benefit in those situations.

The other tax benefit available in the wind energy industry is the combination of tax credits and deductions available for research and development. Where Class 34 is equivalent to a grant of 40 to 45 cents on the dollar, the R & D incentives are equivalent to a grant of between 55 and 65 cents on the dollar. Despite this, this industry has demonstrated that it is much more willing to endure the debilitating trek through the bureaucracy necessary to get grants of 40 or 50 cents on the dollar from EMR or other government agencies, rather than to learn more about the R & D incentives, and put them to use in financing development activities within the industry. Some of the reasons for this lack of penetration are the same as those related to Class 34, but there are other ones particularly associated with R & D.

The first of these is a problem with Revenue Canada. In part because of the problems with the SRTC fiasco, Revenue Canada is now very skittish when it comes to what structures and what activities qualify for R & D tax benefits. It is not at all clear whether Revenue Canada's unwillingness to interpret the Act in this area clearly is their own uncertainty and fear of allowing another SRTC problems arise, or whether Revenue Canada is in fact purposely being vague and difficult in order to discourage the use of the R & D tax incentives. There is some evidence of the latter in Ottawa at the present time. Whatever the reason, the fact is that Revenue Canada has delayed and dried up the access to opinions on the technical qualification of projects under the R & D rules, and to related tax issues of R & D deals. This has become so serious that, in respect of renewable energy, we have asked the Department of Energy, Mines and Resources to assist us in obtaining more certainty on R & D incentives by interceding on our behalf with Revenue Canada or by taking a direct and active role themselves.

The second barrier to utilizing R & D incentives is the fact that the investment community has been lied to so many times about the technical feasibility of R & D programs that it is now reluctant to believe any independent report, even ones from quite reputable organizations. This problem is also true of market analyses showing the supposed market potential of new technological developments. If we in the industry are to obtain the benefits of these R & D incentives, we will have to be very patient in educating the investing public to the advantages of our technological goals, and their actual feasibility and market value. The return of credibility, lost not because of anything our industry did, but nevertheless affecting us in a fundamental way, will only be accomplished with a lot of patience and a lot of disappointments along the way.

Finally, the SRTC's and their aftermath have created an overriding fear within the investment community of anything that sounds like R & D tax shelters. Again there isn't much we can do about that, except to try to be as careful in our presentations as possible, and to be sensitive to the nervousness that investors will have.

Tax Reform

I want to deal briefly with the impact of tax reform on our industry, both positive and negative.

We are all aware, I think, of the fact that the two tax incentives still available to our industry are now almost the only games in town as tax incentives go. All of the other tax breaks have been thrown out entirely or restricted in some respects. While this does not enhance directly the value of the tax benefits available to us, it enhances their value in a relative way. In the Canadian economy, we have been training high income taxpayers for years and years to seek tax shelters at the end of every year. With tax reform, those taxpayers will respond to their training by looking for tax shelters, but will have a much narrower range of products available to them. If we market our industry properly, we can take the lion's share of that very large investment pool.

There are, however, significant negatives for us in tax reform. To a tax specialist, the most obvious negative aspect of tax reform for an industry such as the wind industry is that tax rates have been reduced. Now, for the non-specialist this may seem like an unlikely choice for a negative impact. However, where an industry depends for the majority of its government's support on tax deductions, the net cash value of those tax incentives is directly related to the tax rate of high income taxpayers. A simple example will demonstrate this. If a high income taxpayer invests and gets a $1,000,000 deduction, the value of that deduction at a 55% tax rate is $550,000. That is the amount of tax he will save by getting that deduction. If his highest tax rate is only 40%, then the value of that deduction is only $400,000. As much as tax planning and the design of tax shelters appears to be magical formulae and number crunching, it all really boils down to how much cash the incentive is worth. When the tax rate goes down, the value of the incentive also goes down.

Two technical changes proposed in tax reform will also have an impact. Issue costs will no longer be deductible immediately, but will be spread over five years. This will have the effect of reducing the present value of the deduction for issue costs in tax shelters. The timing of the acquisition of capital properties, including those that qualify under Class 34, has also been changed so that in some cases deductions will not be available until a subsequent year. Both of these changes will have an impact on the tax effects of acquiring wind energy installations.

Many people in the tax community are concerned about the impact of the proposed general anti-avoidance rule on tax incentives such as those available to the wind industry. The difficulty here is not with the intended effect of the general anti-avoidance rule. To the extent that that rule stops sleazy and overly gimmicky tax structures, most in the tax community would applaud it. However, by introducing a high level of uncertainty into tax shelter and tax planning transactions, this new rule is likely to lessen the willingness of high income taxpayers to invest in conservative and conventional tax shelter transactions as well. The practical effect of this is that the amount of money available to finance wind activities on a tax-enhanced basis may be much less than would otherwise be the case.

Finally, and perhaps most important, tax reform signals a philosophical change within the Department of Finance and within the federal government generally. The Department of Energy, Mines and Resources has made it very clear that new tax incentives are simply not a possibility in the present Ottawa climate. It doesn't matter how good the arguments are, or how good the paybacks are, the government is not in the current mood going to consider new tax incentives for anyone, under any circumstances.

If I have one message in this talk, it is what our industry has available to it a huge pool of capital that could be mobilized through the intelligent use of tax incentives. No other industry in Canada has the tax incentives available to it that we do, and it is simply a question of using the same ingenuity that we use on the technical side of wind energy projects to apply the tax benefits to our needs in a creative and aggressive manner.

THE UTILITY PERSPECTIVE

John Martin
Marketing Services
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UTILITY RESPONSIBILITIES

Although TransAlta Utilities is privately-owned rather than publicly-owned, our views on wind-powered electricity generation are probably similar to most electric utilities. If anything, private ownership adds to utility responsibilities in dealing with non-utility generators.

TransAlta Utilities' prime goal is to provide safe, reliable electric service to customers at the lowest possible cost. In achieving this goal, TransAlta has responsibilities to different groups: the consumers who use electricity; the government bodies which regulate our activities; and (for a privately-owned utility such as TransAlta) the shareholders who own the company. Each of these groups has different expectations of the utility. Consumers expect low cost, reliable electric service. Government bodies expect safe, prudent, and competitive operation. Shareholders expect a secure and fair return on their investments. TransAlta must respond to all three group's interests.

TransAlta's goal and responsibilities must be remembered when considering non-utility generation of electricity. If such generation helps the utility provide safe, reliable, and low-cost electricity, TransAlta will support it. If non-utility generation lowers safety standards, lessens reliability, or increases costs, TransAlta will oppose it.

TransAlta is also concerned with setting precedents. Not only must a non-utility generation project stand on its own merits, it must not create opportunity for potential problems with similar future projects. We will invest a lot of time and effort considering an unusual project, to evaluate any precedents it may set.

To ensure that non-utility generation helps provide safe, reliable, low cost electricity to consumers, TransAlta has established guidelines for such generators. In general, the guidelines cover three main areas of concern: technical, contractual, and economic.

TECHNICAL CONCERNS

TransAlta's technical concerns relate to metering of the energy flows between the utility and the generator; safety of the electric system; switching of the electric system and the generator; maintenance of the generator; and effects on the operation of the utility electric system.

The utility is generally accepted as the technical expert in the interaction of the non-utility generator and the electric system. TransAlta sets only those technical standards it considers necessary and prudent. Other agencies, such as the Canadian Standards Association and the local electrical authorities, help by establishing standards for the interconnection of wind-powered and other electric generators.

CONTRACTUAL CONCERNS

A contract usually benefits both TransAlta and the non-utility generator, by establishing terms and conditions of service that are understood and agreed to by both parties. The items covered by an interconnection contract include technical requirements, insurance requirements, pricing, payment and billing arrangement, and contract period. TransAlta has developed a standard Small Power Producer contract, which ensures that both parties know what to expect before a formal agreement is entered into.

ECONOMIC CONCERNS

Economic concerns are generally those with the greatest difference of opinion between utilities and non-utility generators. Three economic factors are associated with an interconnection: the costs of the equipment needed for the interconnection, insurance costs, and purchased power rates.

Interconnection costs are all costs associated with an interconnection above and beyond costs required to connect a utility customer of similar class and load. They include such items as a second meter to measure energy flow from the generator, and any transformer or line changes needed to allow the utility to accept power from the generator. TransAlta keeps such changes to the minimum required for a safe and reliable interconnection. Such interconnection costs should be paid by the non-utility generator. In TransAlta's case, such costs are treated as a one-time expense to be paid by the non-utility generator at the time of interconnection, with no monthly service or operating charges billed for the wind generator interconnection.

TransAlta currently requires non-utility generators to maintain $2,000,000.00 worth of Comprehensive General Liability Insurance including TransAlta as the insured. This seems an appropriate amount in the current insurance climate. TransAlta reviews the amount every year or two, to make sure it is still appropriate, and to ensure the costs of maintaining such insurance is reasonable. Two million dollars worth of liability insurance currently costs from $300.00 to $500.00 annually.

The final economic concern of TransAlta, and the area of most disagreement between utilities and non-utility generators, is power purchase rates. In TransAlta's experience, we can negotiate a rate acceptable to both the utility and a large non-utility generator. But with smaller systems, such as wind generators, neither the small power producer nor the utility want to, or are able to, spend large amounts of time and expense developing individual rates. In general, a widely applicable small power purchase rate is a better approach for everyone.

TransAlta is investigating the effects of small non-utility generators on our electric system and its costs. Groups such as the Electric Utility Planning Council here in Alberta study the value of small power to the electric system. Regulatory agencies have created some solutions, such as the Alberta Energy Resources Conservation Board's "quarterly net energy banking" arrangement. But in general the utility and the small power industry disagree on what constitutes a "fair" power purchase price.

TransAlta has concluded that only an impartial regulatory hearing responsible to electricity consumers, with evidence from both utilities and small power producers, can resolve the issue. In Alberta, such a hearing will begin on October 5th, and will recommend pricing policy guidelines to the provincial government. TransAlta is looking forward to its outcome.

CONCLUSION

TransAlta exists to provide safe, reliable, low cost electricity. In doing so, we try to satisfy consumers, government, and, for private utilities, shareholders. If any venture conflicts with either this goal or any of those three groups, we will be understandably reluctant to try it.

If customer-owned generation will neither lower safety standards, lessen reliability, nor increase costs, TransAlta will generally support it. However, we want to review every project to ensure technical, contractual, and pricing concerns are satisfied.

TransAlta is still learning about wind power and other forms of non-utility generation, as are others in the industry. We may occasionally make mistakes, but we are always trying to achieve long term goals while satisfying short term constraints. Hopefully, problems will get resolved and each of us - utilities, consumers, and the wind industry - can work together to do what we each do best.

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INDUSTRY PERSPECTIVE

Vincent P. Lacey

9/29/87

When I first considered presenting the industry perspective, I wondered what to say, and then it occurred to me that I could share with you the concerns and hopes that are frequently discussed around our company, and obviously by other companies in the industry.

At Indal Technologies, we have been developing wind turbines since the mid seventies and more seriously since the early 1980's.

In the early development stages, building machines was strictly a question of technical risk. No-one expected to make any money, but we hoped to learn how to make them better. This was later followed by efforts to make technically reliable machines economical. As the design tools have improved, the reliability issue has become easier to deal with, because this element is almost totally within a company's control.

However, economic pressures often force companies to cut this too close to the line. The difficulty for most companies is the balancing act between technical and financial risk. Today we can make a machine that is almost 100% reliable and a twenty-year design life is in sight. It is often the case, however, that you cannot sell these machines in small quantities and naturally this is the most difficult part. With increased quantities, economic production can be achieved. In the meantime, companies have to subsidize the business or take risky short cuts.

Forecasting the time for the market and economic production to merge is practically impossible, due to the high degree of influence from external factors. Oil prices, tax incentives and subsidies, environmental factors and economic growth all play a role in the equation, and the best forecasting cannot really predict the commercialization date any closer than 5 years. This is exacerbated by the relatively long periods of test and development time to prove the product. If you leave the development effort until the market emerges, you will not be able to respond in time. Competitors are likely to be already better positioned.

(continued..........)

So you balance the investment against the risk that the market may take a very long time to emerge.

Without a tax credit system in this country, the sharing of risk can only come from government and electric utilities. Naturally those groups would prefer that companies take all of the risk, but we have to be realistic. Difficult technological achievements are rarely developed anywhere in the world solely with investors' funds, and after all, the benefits are usually shared by many. If we are to compete, we have to recognize that we compete in a global economy where this is well understood.

What is encouraging, but at the same time somewhat disturbing, is the utilities are beginning to buy these machines for commercial operation, while at the same time even the largest electric utilities are closing down their R & D programs. This results in a transition from experimenting with wind turbines, advancing slowly in reliability and performance to a requirement that they be 100% reliable and economic. Not all machines have reached that stage, but some companies have been forced to accept these conditions in order to survive. I believe this approach is unrealistic and could lead to disappointment in these so-called "commercial" installations.

Naturally the government would like to see the industry stand on its own two feet today. Programs that have a ribbon-cutting ceremony fifteen years after their inception can hardly be called politically desirable. However, if utilities and governments expect instant and unsubsidized commercial success, they may be in for a let down.

Most companies struggle on in the belief that electricity prices are subsidized by tax revenues or unpaid debt and that wind turbines can, and will compete on an equal basis when the subsidies become available to wind energy, or removed from so called "conventional" energy.

This is coupled with the belief that nuclear and other large scale capital intensive projects have become extremely difficult to deal with, and that a mix of smaller diverse sources will become desirable for both economic and environmental reasons.

If we all begin to look no further than next quarter's profits or budget allocations, we may not see developments in Canada using Canadian machines. We need to restore and intensify the cooperation that got the industry this far, or the basis that the benefits to be reaped are worth waiting for.

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